

**Controlled and efficient processing of psychological and
spatial perspectives in children and adults**

by

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Abstract

Eight experiments investigated psychological and spatial perspective-taking in children and adults. Experiments were designed to identify under what circumstances and at what stage of development computing the perspectives of others is cognitively effortful and when it is cognitively efficient.

Level-1 perspective-taking requires judgements of *whether* or not another person can see a given object. Level-2 perspective-taking requires judgements of *how* another person sees a given object. Using an indirect measure of perspective-taking, Experiments 1-3 found Level-1 perspective-taking to be somewhat automatic, even in children, whilst we found no evidence of automatic Level-2 perspective-taking. Using a direct measure, all forms of perspective-taking required cognitive control and were susceptible to egocentric interference. Such interference is a feature of perspective-taking of both children and adults and in Experiment 4 it was shown to be related to individual differences in executive function. In Experiments 5A and 5B children and adults made spatial frame of reference judgements, in where they integrated information from their own spatial viewpoint and that produced by the frame of reference of an object or agent.

Perspective-taking makes conflicting demands for efficiency and flexibility on cognitive systems. This thesis lends support to the idea that one way these demands are resolved is through distinct systems with distinct processing features.

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CHAPTER 1

Introduction

1.0 Introduction

Understanding the beliefs, desires, intentions and perspectives of other people is important in predicting and interpreting their behaviour and in guiding our own. Such abilities are often grouped together and considered within a single concept, variously referred to as Theory of Mind, Mentalising, Mindreading or Folk Psychology. Since Premack and Woodruff (1978) asked whether the chimpanzee had a Theory of Mind, 30 years of research into these abilities has mainly focussed on how typically (Wellman, Cross & Watson, 2001; Wimmer & Perner, 1983) and atypically developing children (Baron-Cohen, Leslie & Frith, 1985) first gain such abilities. Located within a wider discipline of cognitive development, such studies have been multiple and informative. Notwithstanding this, it is hard to argue that we actually have anything close to a complete picture of the cognitive processes involved in Theory of Mind, and for that matter how these processes develop. This thesis will focus on various aspects of that very problem.

1.0.1 Problems posed by Theory of Mind on cognitive systems

Theory of Mind (ToM) poses two conflicting problems (Apperly & Butterfill, 2009). On the one hand ToM must occur on-line and quickly: to keep up with rapidly moving social situations we often have to make judgements in a very short time period, otherwise the information becomes redundant. Conversely, ToM judgements often require the integration of large quantities of varied information; flexible off-line judgements guarantee a greater chance of success. Resolving these, often contradictory, demands causes one of the greatest problems to research in this area.

1.0.2 Focuses of research on Theory of Mind

Whilst it seems clear that ToM is involved in many aspects of social functioning, what is much less clear is how we can test when and how people are computing the mental states of others. Many theories of ToM posit a role for automatic and efficient on-line ToM (Leslie & Thiass, 1993; Sperber & Wilson, 1986), but the paradigms generally employed in ToM research may be largely irrelevant in testing this. Specifically, most research on ToM has tended to ask children to make judgements under no time pressure and with very limited demands beyond those required to perform the judgement itself. Whilst informative about the flexibility and capacity of people's ability to reason about mental states, such studies have left us largely uninformed about how on-line or efficient ToM might operate.

As well as focussing on testing just one kind of ToM judgement, until recently, research in ToM has also largely been restricted to one age group, pre-school children. More recently, there has been some progress on this, with the field expanding to test ToM abilities in infants (Onishi & Baillargeon, 2006; Sodian, Theormer & Metz, 2007; Song & Baillargeon, 2008; Southgate, Senju & Csibra, 2006) and non-human animals (Call & Tomasello, 2008; Emery & Clayton, 2004; Santos, Flombaum & Phillips, 2006) more regularly. Other work has begun to ask the question of whether there are any limits to the abilities of adults (Epley, Morewedge & Keysar, 2004; Keysar, Lin & Barr, 2003; Samson, Apperly, Braithwaite, Andrews & Bodley-Scott, 2010) and also to actively test whether (and perhaps more importantly under what circumstances) ToM is automatic or spontaneous (Apperly, Riggs, Simpson, Samson & Chiavarino, 2006; Back & Apperly, 2010; Cohen & German, 2009; Kovacs, Endress & Teglas, 2010; Samson et al., 2010).

1.0.3 This thesis

This thesis aims to directly address some of the problems raised by the conflicting demands on ToM. Specifically, I will explore the roles for efficient and controlled processing of ToM using tasks that allow for testing of adults as well as children and measure efficiency of ToM as well as flexibility. By testing older children and adults it is possible to detail what constitutes a mature ToM and also how children develop towards this. Improvements made by children after early childhood have widely been attributed to increasing general processing resources. In the current thesis, I will investigate whether this assumption is necessarily the case and will also propose that where general processing improvement does underlie quantitative development, this does not make such development any less informative. To understand day-to-day ToM, investigating the fluency and capacity that prescribe the limits on *actual* ToM performance is just as important as investigating the “concepts” that prescribe the limits on *possible* ToM performance (See Samson & Apperly, 2010 for a recent review of this suggestion).

This thesis contains 5 experimental chapters. Chapters 2-4 focus on elements of control and automaticity in visual perspective-taking. Chapter 5 examines the links between ToM and executive functions in middle childhood. Chapter 6 looks at one case in which automaticity vs. control in perspective-taking plays a role in spite of no explicit perspective-taking being required; that is in judgements about spatial frames of reference with social stimuli.

1.1 Controlled, Effortful Processing of ToM

The paradigms employed in Chapters 2-5 all contain conditions in which participants are actively asked to take the perspective of someone else. In other words, they are asked to make explicit ToM judgements and respond in line with them. This sort of perspective-taking we will consider to be controlled as participants actively select responses in line with their perspective-taking.

1.1.1 An example of what effort affords

The British legal system (along with most others in the world) makes a distinction between Murder and Manslaughter on the basis of intention (A similar distinction exists between *Attempted Murder* and *Grievous Bodily Harm*). As a member of a jury, (largely) untrained members of the public have to decide whether the defendant intended a given action. Important outcomes for the defendant, the victim's family and potentially society as a whole, rest on the jury making such judgements with accuracy. To make this decision correctly the juror may need to interpret a large amount of information to impute mental states of others and then flexibly interpret how these mental states might predict certain intentions and thus behaviours. The fact that we expect jurors in such cases to make decisions "beyond reasonable doubt" (oh hang on, do we then need to impute another mental state to work out how much doubt it is "reasonable" for a person to have...) suggests that humans consider this task achievable, if difficult. We should expect the processes involved in this sort of decision making to trade for flexibility and capacity in the quest for accuracy. Up to a point, the speed with which such decisions are made is inconsequential, what matters is the range of information we can successfully incorporate. This is an important point, as later we will discuss ToM which makes precisely the opposite trade off.

1.1.2 Tests of children's flexible ToM

Most tests of ToM in young children have investigated flexible decision-making. Children have generally been asked to make single judgements under no time pressure. Results from these studies have provided a fascinating insight into the limits of young children's reasoning when confronted with such problems. Perhaps most famously, false belief tasks have demonstrated very clearly that pre-school children make errors when making these sorts of judgements (Hogrefe, Wimmer & Perner, 1986; Wimmer & Perner, 1983; Wellman et al., 2001). In the classic false belief-change of location task (Wimmer & Perner, 1983), a boy, Maxi, puts his chocolates into a drawer and then goes out to play. Unbeknownst to Maxi, while he is out playing, his mother moves his chocolates from the drawer to a cupboard. Maxi returns to the scene and children are asked to predict where Maxi will look for his chocolates. Adults, almost exclusively, predict that Maxi will look in the drawer where he originally left his chocolates. At the age of three, children across a wide range of cultures and settings mostly fail this task (Wellman et al., 2001). At the age of four, most children pass this task. Three-year-olds do not fail this task at random, for instance suggesting Maxi will look under the table, or using semantic knowledge (there is no reason why any location is more commonly associated with chocolates), rather they expect Maxi to share their own, correct, knowledge of the location of the chocolates.

Similar demands on reasoning are thought to be made by false belief- unexpected contents tasks (Hogrefe et al., 1986). In the classic version of this task, children are shown a "Smarties" tube and asked to guess its contents. After reporting that they expect Smarties to be inside, children are shown that the tube actually contains

pencils. They are then asked what another child would think would be in the tube when confronted with it for the first time. As with the change of location task, most 4-year-olds respond like adults, they expect another person to predict Smarties to be in the tube, but most 3-year-olds predict that the new child will correctly guess that the tube contains pencils. The incidental demands of unexpected contents and change of location tasks are really quite different, suggesting that the effects found are really not just due to the methods themselves. Modifying these experiments can make marginal changes to the precise age at which children can pass this task. For example, by including a temporal marker such as “where will he look first?” or by increasing the salience of the protagonist’s belief children pass these tasks marginally earlier in development (Wellman et al., 2001). Importantly though, over the course of 25 years of research, these findings have been largely robust.

1.1.3 Converging success around the age of four

Aside from false belief tasks, a number of other ToM abilities emerge around the age of four years. This is a similar age to when children are first able to pass Level-2 visual perspective-taking tasks (Flavell, Everett, Croft & Flavell, 1981; Masangkay, McCluskey, McIntyre, Sims-Knight, Vaughn & Flavell 1974). Level-2 visual perspective-taking requires an understanding that someone else may see an object differently from oneself. In Chapters 3 and 4, we will provide the first studies designed directly to look at Level-2 perspective-taking in older children and adults. Level-2 perspective-taking can be thought to be similar to false belief tasks in requiring conflicting representations about a single item. Also, children around the age of four begin to make the distinction between appearance and reality (Flavell, 1999; Flavell, Flavell & Green, 1983). The convergence of evidence of a shift in

performance around this age on tasks involving seemingly different concepts suggests that children's performance cannot be explained by the acquisition of a suitable concept of false belief alone. If the acquisition of conceptual apparatus is to explain children's performance, either a more substantial concept(s) of the minds of others, or a concept(s) that is not specific to the domain of ToM must be acquired. One suggestion (Perner, 1991) is that children have to acquire a suitably refined concept of representation, which is general across many domains (this idea is discussed in section 1.1.7).

1.1.4 Early success

Recent studies showing infants' success in tasks that appear to require ToM have used indirect measures where no controlled response is required (Onishi & Baillargeon, 2005; Sodian, Theormer & Metz, 2007; Surian, Caldi & Sperber, 2007). I will discuss these findings more in section 1.2 when I consider ToM that is achieved in a manner that is efficient. There is, however, also good evidence of success by children before the age of four in tasks that demand controlled responses. Before passing false belief tasks, children make correct explicit decisions about Level-1 visual perspectives (the ability to understand whether or not someone sees a given object, Masangkay et al., 1974; Moll & Tomasello, 2005) and can also make explicit judgements about what different people will do based on diverging beliefs (Bartsch & Wellman, 1989). Pre-school children have also been demonstrated to show some knowledge of intention (in their imitation; Meltzoff, 1995) and about diverging desires (Rapacholi & Gopnik, 1997).

1.1.5 What four-year-olds still have to learn

The youngest children tested in the experiments detailed in this thesis were 6-years-old. Whilst for the most part I will justify this strategy in allowing for testing the development of specific cognitive processes involved in ToM, there are still tasks that children fail after they can consistently pass standard false belief tasks. Some of these tasks involve the concept of referential opacity, and are generally failed until around the age of 6-7 (Apperly & Robinson, 1998, 2001; Russell, 1987). Such problems require the ability to understand that a given person or thing may have more than one reference, which may not be known to all. For example a boy, Mark, may know Mrs. Barclay as his class teacher. If Mrs. Barclay has to rush home ill one day, and Mark is aware of this, we can safely assume that Mark will correctly answer the question “where has your teacher gone?” Mrs. Barclay as well as being Mark’s class teacher, may also be the mother of another child in the school, Michael. If Mark does not know this, it would be wrong to assume that Mark could correctly answer Michael’s question “where has my Mum gone?” Whilst adults seem to find such opacity relatively easy to understand (and authors such as Shakespeare, Sophocles and Dostoyevsky have taken advantage of it for humour, tragedy or suspense), children up until the age of 6 or 7 respond as if they assume that all references available to them are necessarily available to others.

It is also the case that the ability to understand some complex social situations develops well beyond the age at which children pass standard false belief tasks. Baron-Cohen, O’Riordon, Stone, Jones and Pliasted (1999) tested children’s ability to understand faux-pas and found development from 7-years of age up to the age of 11. Faux-pas situations involve individuals making socially inappropriate comments or

behaviours, often because of being only partially informed about others. Ability to understand irony and sarcasm is thought to develop somewhere between the age of 6 and 12 (Capelli, Nakagawa & Madden, 1990; Creusere, 1999; Demorest, Meyer, Phelps, Gardner & Winner, 1984; Winner & Leekam, 1991). Again such abilities require subtle social understanding, in this case understanding that others may not only deliberately communicate something that contradicts that person's knowledge or beliefs, but also that they may do so in the knowledge that others will understand that this is what they're doing. Whilst these abilities do develop beyond the age at which children pass false belief tasks, it is generally thought that they do not require new concepts as such, rather a greater flexibility in use.

Even within the area of reasoning about beliefs and desires some more complex tasks are failed by children after the age at which they pass standard versions of the task (Leslie, German & Polizzi, 2004; Leslie & Polizzi, 1998; Wimmer & Perner, 1983). Many theories of human communication require humans to impute recursive mental states (Sperber & Wilson, 1986; Tomasello, 2008), for example, it is proposed that when we communicate, we do so in a way that demonstrates that "*You know that I know*" given information, or that I know that "*You intend me to know*" certain things (Tomasello, 2008). Interestingly, when such reasoning, involving mental states about mental states, is tested explicitly (using so-called second order false belief tasks), children fail such tasks until around the age of 6 (Wimmer & Perner, 1983). In such tasks, children may, for example, have to reason about what one character will do based on her false belief about the beliefs of another character. Whilst such scenarios seem quite complicated, it is really worth emphasising that this is exactly the sort of reasoning many believe that mature communicators are able to do without demanding

extensive cognitive resources (Sperber & Wilson, 1986; Tomasello, 2008). It is not just these second order tasks which cause children problems, however, similar performance is found on tasks requiring children to reason about false beliefs and avoidance desires (Leslie & Polizzi, 1998; Leslie, German & Polizzi, 2005). An avoidance desire, in these circumstances, is held by an individual who wishes, only, to avoid a given item. For example, Friedman and Leslie (2004) asked children to reason about where a character would place her dress given that she knew one of the locations to contain a dirty frog. Clearly, here, her only desire is to avoid the dirty frog and within the boundaries of the paradigm she should aim for an empty box. When children have to reason about such desires paired with false beliefs; for example, she wishes to avoid the frog, but wrongly believes it to be in a given location, they fail these tasks until around the age of 6 (Leslie & Polizzi, 1998; Leslie, German & Polizzi, 2004). Leslie and colleagues have suggested that such tasks require no more conceptual knowledge, but are more demanding of executive resources (Leslie & Polizzi, 1998; Leslie, German & Polizzi, 2004). In Chapter 5 I include a task which specifically requires children to reason about these composite belief and desire problems (Adapted from Apperly, Warren, Andrews, Grant & Todd, in press). In comparing individual differences on this task with individual differences in executive functions, I will address some of the reasons why such problems are more difficult than reasoning independently about either false beliefs or avoidance desires.

1.1.6 Summary

When children are asked explicitly to make judgements about others' mental states, findings are fairly consistent. There seems little doubt that there is a shift in

performance in this flexible and controlled reasoning about ToM around the age of 4; although this is by no means the beginning or the end of development in flexible ToM reasoning or use. There has, however, been heated debate over how we should explain this shift in children's performance. Whilst the children and adults tested in the following experimental chapters have clearly undergone this development, how this shift in performance is explained goes some way towards outlining some of the major theoretical stances across the literature as a whole, I will treat each potential explanation relatively cursorily at this stage, hoping to cover only the elements that relate to explaining children's explicit reasoning about mental states. Many of the issues raised will be returned to in further discussions as what underlies this shift in performance is highly relevant to the empirical data presented in Chapters 2-6 and how we should view controlled processing of ToM as a whole.

1.1.7 Representational Shift

One interpretation of the results that a wide range of tasks involving the ability to reason about others' thinking and behaviour changes around the age of four is that this marks the emerging ability to metarepresent, (Perner, 1991). Metarepresentation involves the ability to understand representations as representations (Leekam, Perner, Healey & Sewell, 2008). This is, of course, a general ability also required outside of the social domain. For example, in False Sign tasks (Parkin, 1994) a sign points that an object is in a given location, the object is then moved and children have to report where the sign shows the object to be. In other words, children must understand that the movement of the object itself is not relevant to the content of the representative sign. Interestingly, Parkin (1994) found performance on a false sign task to correlate significantly with performance on a standard False Belief task. False Photograph tasks,

in which a photograph representing a past state of the world that is now incorrect (Zaitchik, 1990), have also been suggested to control for general demands of false belief tasks. Performance on False Photograph tasks have also been found to correlate with False Belief performance (Zaitchik, 1990; and are often used as a control condition in neuroimaging studies of ToM; Saxe, Carey & Kanwisher, 2004). Interestingly, though, False Belief performance and False Photograph performance do not always converge (perhaps most interestingly in studies of autistic children who tend to pass False Photograph tasks, but not False Belief tasks; Leekam & Perner, 1993). Perner and Leekam (2008) suggest that this is because the False Photograph task does not successfully match the metarepresentational demands of the False Belief task. False Photographs are not in fact “False”, for they do not mis-represent information, but rather accurately represent information at a different time. Importantly, Maxi’s false belief about the location of chocolates is false because maxi *thinks* that the chocolates are in the drawer, not because he *thought* they were when he saw them placed there. Some support for this view (in addition to its apparently sound logic) comes from the fact that the relationship between performance on False Belief and False Sign tasks remains significant even when False Photograph performance is controlled for, whilst False Photograph performance no longer correlates with False Belief performance if False Sign performance is controlled for (Leekam, Perner, Healey & Sewell, 2008). Evidence of such a close relationship between False Belief and False Sign performance suggests that general cognitive abilities, such as the ability to metarepresent, may be crucial in passing False Belief tasks. If the ability to metarepresent underlies the significant shift in performance around the age of four, one might predict qualitatively similar performance after this age (with general

resources for processing information prescribing performance based on their general demands).

1.1.8 Performance Shift

Another alternative is that the apparent qualitative shift in performance around the age of four is the result of quantitative increases in general executive abilities (Leslie & Thaiss, 1994; Scholl & Leslie, 1998). For this viewpoint, the change in children's abilities supposes that children, even before the age of four, have all the conceptual ability necessary to reason about concepts such as false beliefs, but that what is difficult is some specific part of the tasks which test these abilities. Particularly, it could be suggested that what is difficult in ToM tasks is the ability to ignore one's own perspective when making the judgement to respond as to the content of another's belief/desire/perspective. Whilst avoiding answering purely from your own perspective is clearly an important part of reasoning about another's mental states, it is not necessarily involved in creating a representation of a mental state of another. Leslie and colleagues (Leslie, German & Polizzi, 2005; Scholl & Leslie, 1999, Scholl & Leslie, 2001) suggest that there are two components involved in ToM. Firstly, a Theory of Mind Module (ToMM) that represents the mental states of others and secondly a Selection Processor responsible for selecting between mental states to use in responding. The ToMM is proposed to be an innate module allowing for representation of others' beliefs, whilst the selection processor must develop in line with developments in executive functioning to allow children to "pass" standard, explicitly framed ToM problems.

Performance accounts will be particularly relevant to discussion of the findings in Chapter 5, in which we investigate the role of the executive functions in ToM in children, but also relevant throughout each of our studies that chart processing difficulty. A performance account would predict that conditions and tasks that are failed by children at an early age will still be most demanding of the resources of older children and adults. Showing this is not sufficient to validate a performance account, but is necessary.

1.1.9 Competence Shift (Russell, 1996)

Errors made in ToM tasks may correspond to a limit to executive functions, but this does not necessarily mean that they are uninformative about ToM itself. Whilst Leslie and colleagues suggest that the links between ToM performance and executive functioning are largely due to superficial elements of the task and occur after a ToMM has imputed the relevant mental states, Russell (1996) suggests another alternative: that executive functions may be crucial to forming the ToM concepts themselves. It is suggested that the increasing sophistication of such concepts, brought about by developments in executive control, leads to success in traditional measures of ToM. A competence account, like a performance account would predict that the most demanding conditions for adults and older children would be those that are the latest to be passed in children's development. Unlike a performance account a competence account should predict that some abilities should be unavailable to sufficiently young children, regardless of how far we reduce incidental task demands (or to put this another way, it may be that sufficiently reducing incidental task demands is impossible).

1.1.10 The Executive Functions

So far, whilst talking of controlled processing of perspectives, controlled processing itself has perhaps been rather undefined. By controlled processing, I include all processing that is not automatic, rather that it requires a role for deliberate, effortful action. If there is a role for controlled processing in ToM, which seems relatively clear, a question still remains: When and how do we utilise control? Particularly, if we decide to take the perspective of another, how can we hold in mind another's perspective, switch to it and ignore our own when making a decision? Even such a superficial analysis of the demands of ToM could be seen to suggest a role for the Executive Functions in ToM.

The executive functions are a set of related yet independent abilities commonly found to recruit brain activity in the frontal lobes (Collette et al., 2005; Hwang, Velanova & Luna, 2010; Luria, 1973; Miller & Cohen, 2001). They are thought to be responsible for the planning, enacting and termination of complex thinking and behaviour. Whilst there is debate about exactly what components make up the executive functions, there is some consensus behind a tripartite division (Collette et al., 2005; Diamond, 2006; Fisk & Sharp, 2004; Miyake et al., 2000). Executive function can be divided into the subcomponents of inhibition, task switching and working memory.

Chapter 5 of this thesis focuses on the link between Executive Functions and ToM in middle childhood. Whilst only one chapter specifically addresses this aspect of control, the ideas from it are prevalent throughout. ToM and Executive Functions are known to be strongly linked (Carlson & Moses, 2001; Hughes & Ensor, 2007). As I will show evidence of continuing development in ToM beyond the age of four, what

underlies this development becomes a significant question. As there is known to be evidence of significant developments in the executive functions after the age of four (Davidson, Amso, Anderson & Diamond, 2006; Simpson & Riggs, 2005), these executive developments provide a plausible hypothesis for the underlying cause of improvements in ToM. As there is meaningful variability in older children (Davidson et al., 2006) and even adults (Miyake et al., 2000), such a hypothesis is not only testable, but may have some part in explaining individual differences in, as well as development of, ToM.

1.2 Automaticity, Spontaneity and Efficiency

Whilst much of what might be considered ToM seems to be very demanding of cognitive resources, recent research has highlighted that this is not always the case. Whilst the majority of three year olds fail false belief tasks when they have to provide explicit responses, when infants' looking time is considered, they seem to show sensitivity to the mental states of others (Kovacs, Teglas & Endress, 2010; Onishi & Baillargeon, 2005; Sodian, Theormer & Metz, 2007; Southgate et al., 2007; Surian, Caldi & Sperber, 2007). Also, similar, indirect, measures have suggested some success in these abilities in Chimpanzees (Call & Tomasello, 2008), Macaques (Santos et al., 2007) and Western Scrub-Jays (Emery & Clayton, 2004). Clearly, infants and the non-human animals mentioned, whilst impressive in their performance, are limited in cognitive resources. Importantly, they are limited in the very executive abilities thought to be crucial for ToM. It is also the case that infants' and non-human animals' lack of abilities in language should predict very poor performance. Language has been strongly linked to performance in ToM tasks (Astington & Baird, 2005), with both syntactic ability (particularly the ability to

embed propositions, de Villiers and de Villiers, 2000) and semantics (Cutting & Dunn, 1999) predicting performance on standard false belief tasks. Language does, however, seem to be more important in developing ToM abilities than passing theory of mind tasks (Apperly, Samson, Carroll, Hussain & Humphreys, 2006; Astington & Jenkins, 1999). That infants and non-human animals show, even basic, ToM abilities suggests that there must be routes to success in ToM that do not require substantial language or executive abilities.

1.2.1 How ToM can be achieved with limited resources

Much of the next three chapters of this thesis addresses the question of how ToM can be achieved with relatively few resources. Added to evidence of studies from infants and non-human animals, a recent study by Samson et al. (2010) evidenced a possible route to such efficient ToM in adults. Specifically, Samson and colleagues tested adults using a Level-1 visual perspective-taking task and showed that they were taking the perspective of another in the scene in a somewhat automatic manner. In Chapter 2 I investigate whether such automaticity generalises to children as well as adults. My interest in automaticity comes from its association with efficiency (Bargh, 1994). The main gain from processing information automatically is that it frees up cognitive resources and saves valuable time and this is something we would expect an efficient system to trade in favour of. Whilst the main point of principle for the current thesis is efficiency, an important issue to raise at this stage is what we mean by automaticity, which has been characterised in a number of different ways.

1.2.2 Automaticity

One of the most influential descriptions of automaticity (particularly for those interested in social cognitive processes) comes from Bargh (1994) who described what he termed the “four horsemen of automaticity”: these being Intentionality, Controllability, Efficiency and Awareness. It is worth being aware that most researchers see some element of flexibility in how processes should be considered, and Bargh (1994) points out that “mental processes at the level of complexity studied by social psychologists are not exclusively automatic or exclusively controlled, but are in fact combinations of the features of each.” (Bargh, 1994; p3). This may be highlighted by recent research which suggests that certain highly efficient processes may be, to some extent, accessible to certain elements of top-down control (Teufel, Fletcher & Davis, 2010). For example, even if automatic following of gaze may not occur when a participant *believes* another not to be sighted (Teufel, Alexis, Todd, Lawrance-Owen, Clayton & Davis, 2009), this does not suggest that gaze following does not show many of the relevant features of automaticity. It may often depend on the theoretical use to which the automaticity of a given process is put to determine the importance of given elements of automaticity. For the discussion of visual perspective-taking in Chapters 2-4, there are two things which are of interest in whether visual perspective-taking is automatic or not. Firstly, if a process is automatic, then it would generally be considered not to require extensive cognitive resources. Evidence that visual perspective-taking is not demanding of significant cognitive resources may help to explain how infants and non-human animals manage to process perspectives to some degree and how adults can manage rapid on-line tracking of the perspectives of others. Secondly, as we are interested in how cognitive processes for ToM develop, such a bifurcation of processes into automatic and

controlled may allow for a greater understanding of what extra cognitive resources really allow us to achieve.

1.2.2.1 Intentionality

The intentionality of a process is related to what drives the process: is it driven by an internal decision of a person to do so or a direct response to a stimulus? For the purposes of this thesis we will take participants' intentions to be linked to the task which they have been asked to complete. This does not preclude that they may introduce alternative strategies (or intentions), however I will argue, for the most part, that it is safe to assume that if participants are acting in a way that is actively detrimental to their performance on the task then they are not doing so intentionally.

1.2.2.2 Controllability

Controllability, like intentionality, relates to an individual's ability to manage a given process. Whilst intentionality refers to the initiation of a process, controllability refers to its continuation; i.e. can we stop the process once it has begun? This is perhaps the most discussed area of automaticity and many consider any evidence of top-down influences on processes to mean that the process is necessarily non-automatic. Controllability is a tough concept to define. Participants can clearly close their eyes to avoid a visual stimulus that might otherwise trigger an automatic response. For the current discussion, our consideration is in fact similar to that of intentionality. Specifically we make the assumption that if a given process is having a detrimental effect on task performance, then participants are unable to control it (or it at least costs them significant cognitive effort to do so). Importantly in the experiments in Chapters 2-4 participants will receive the crucial information as to whose perspective

they should take *prior* to each picture stimulus. This means that participants have the option of strategically preparing for processing the stimulus. We will assume that if they can control their processing, part of their strategy will be to do so.

1.2.2.3 Efficiency

If a process is automatic it should be computed efficiently. This is, in fact, the element of automaticity that interests us most in the following chapters. If visual perspective-taking is shown to be automatic, and therefore efficient, then this may go some way to explaining the success of infants and non-human animals. By Bargh's (1994) definition, the efficiency of a process refers the extent to which the process demands attentional resources. In fact, for our purposes, we will extend efficiency to include making limited demands on executive resources as well. If an efficient mechanism for perspective-taking were to be of use in explaining the performance of infants and non-human animals, it should make limited demands on memory and inhibition as well as on attention and it should also be able to operate without language. This is what could plausibly allow perspective-taking to occur in very young children and non-human animals and when adults are clearly dedicating significant resources to other aspects of social interaction. For my current purposes, I will take a process to be efficient if participants remain able to complete a task which is demanding of general resources. For the perspective-taking tasks used this will involve participants actively having to make a judgement about their own perspective on a scene.

1.2.2.4 Awareness

That a process occurs without the awareness of the processor is the final "horseman" of Bargh's automaticity. There are many different forms of awareness, varying from

whether a person is unaware that they have even seen a stimulus (subliminal influence) to simply unaware of the influence it has had on their decision making (Bargh, 1994). In Chapters 2-4 we will put only limited demands on participants being unaware of any automatic perspective-taking process, other than to make the assumption that if participants were aware of their automatically taking the perspective of another, they would make active attempts to use this when making judgements from that perspective and to avoid doing so when judging a secondary task. Lack of awareness is also less essential here as awareness does not necessarily reduce efficiency and thus, does not necessarily speak to this as a plausible explanation for the success of infants and non-human animals.

1.2.2.5 Summary

In summary, I will place two main criteria on our investigations of the automaticity of visual perspective-taking. If visual perspective-taking is automatic, participants should take the perspectives of others in a way that actively hinders their performance on another task. Also, this should be the case even when participants have prior information that taking the perspective of another is *not* their task. In addition to these main criteria, to confirm that it is truly social perspective-taking that is automatic, such effects should not be replicated in non-social control conditions.

1.2.3 Original Automaticity and Automatisation

If the automaticity of perspective-taking is to be important in the discussion of the development of ToM it is just as vital *how* the process has become automatic as whether the process is automatic or not. Specifically, as I will discuss in Chapters 2 and 3, the degree to which automatic processes found in adults may provide

explanatory power for the impressive abilities of infants may rest on whether these processes are *originally automatic* or whether they are *automatised*. The important difference between these two alternatives is in their development. Specifically an *originally automatic* process is a process that emerges as an automatic process, i.e. it is efficient and outside of cognitive control from the beginning. For example, it is thought that infants have an innate pre-disposition for processing small sets of numbers (Feigenson, Dehane & Spelke, 2004). Importantly, infants have this ability before they can explicitly report knowledge of, or have any training in, the counting process. If a process is *automatised*, it begins as a process that requires cognitive control, but with exposure and practice the need for cognitive control and attentional resources becomes reduced. A good example of this is in the automatisisation of addition (Lefevre, Bisanz & Markonjic, 1988). It is clear that formal addition of numerals cannot be initially automatic (for different cultures have used different number systems), however, with exposure cognitive control is no longer needed to calculate familiar sums with small numerosities.

1.3 Reconciling Efficient and Controlled Processing

To a greater or lesser degree, theories of ToM have acknowledged the role for both efficient and more effortful processing of others' mental states. Such accounts can be loosely classified on the basis of how they expect that efficient ToM may work, and what they expect it to achieve. Differences are particularly clear when examining different explanations of the success of infants in tasks which seem to require ToM. Whilst the empirical findings in the following chapters assess more specifically the development towards a mature, efficient, effective ToM, explanations of infants' performance are highly relevant.

1.3.1 Infant Mentalisers and the Modularity of Mind

Given the consistent evidence from studies with young children (Welman et al., 2001), the fact that infants' looking behaviour suggests any knowledge of the beliefs or perspectives of others is quite remarkable. One way of interpreting these findings is to suggest that these tasks have been able to demonstrate infants' true abilities by removing irrelevant task demands placed by less sensitive measures. To this way of thinking, infants' ToM has all the essential sophistication of that of adults, though not necessarily all the general information or executive abilities required to perform in the same way. Onishi and Baillargeon (2005, p255) make the bold proposition that 15-month old infants "...realize that others act on the basis of their beliefs and that these beliefs are representations that may or may not mirror reality". This echoes the sentiments of Leslie on the "specific innate basis for our common-sense theory of mind" (Leslie, 1987, p424). Leslie and colleagues propose that efficiency is the results of an encapsulated theory of mind module processing specific inputs (Leslie & Thaiss, 1993; Scholl & Leslie, 1998). A module is able to achieve efficiency as it operates on a very restricted set of inputs and produces a very specific set of outputs.

Modular accounts for cognitive processes in general are influential and encapsulation provides much explanatory power. Fodor (1983, 2001) proposes that modular processing helps to address the frame problem, or problem of relevance. This is the problem of how cognition can possibly work when the potential information that could be used in any problem is unbounded (this is relevant to concerns about how ToM can be both flexible and efficient). Specific, bounded, modules help to avoid the problem of relevance as they are encapsulated; they do not need to *consider* information outside of a very strict set of inputs and thus can operate efficiently.

Importantly, such encapsulation comes at a cost: a cost of the hard constraints on such modules. If only a very specific set of inputs can be processed, then only a specific set of real world situations can be negotiated. For a cognitive process such as vision, such hard constraints may not cause such a problem (though they do give rise to perceptual illusions); all important inputs could be seen to be relatively similar. However, for a complex, higher cognitive, problem such as are encountered in ToM, such constraints may cause major problems. Can we really expect a module to track the content of another's visual perspective and also their beliefs about the role of the monarchy in a post-colonial world? Of course, Leslie and colleagues do not suggest that all specific information on beliefs can be processed innately, rather that the systems for belief reasoning are innately pre-described.

Whilst Leslie and colleagues are clear in their suggestion that a ToMM generates mental states of others, which are then coordinated by a separate Selection Processor which develops with age (Leslie & Thaiss, 1993; Scholl & Leslie, 1998), they are less clear on where the limits lie to this kind of processing. Scholl and Leslie propose that a modular theory of mind may only be considered as “early theory of mind” and also that aspects of this may “be triggered by the environment during maturation”. There is really very little attention paid, however, to how these processes are divided, or even to whether it is possible to test this. In other words, Leslie and colleagues suggest two processes by which ToM can be achieved: One route which involves automatic and involuntary processing of perspective which is subsequently organised by the Selection Processor, but also a much less defined route for “later” or “triggered” ToM (which may also require the Selection Processor). A big question remains as to

whether and if so, how, such later or triggered ToM can account for the flexibility achieved by ToM.

1.3.2 Core Cognition

I strongly believe that it is worth defending the notion that some form of ToM can be achieved through an encapsulated, modular-like process, though of course this does not mean that it is always done in this way. *Modular* or *core* processing clearly provides one route to efficiency and success by increasingly young infants suggests the likelihood that some abilities may be innate. I find it unlikely, however, that all ToM is achieved in this way as such a system would be predefined to operate on a very specific set of inputs, chosen for their adaptive advantage, which would strictly limit such a system. Accounts of core cognition in developmental psychology (Carey, 2009) more easily afford a role for both innate abilities and significant future development than purely modular accounts.

Core conceptual systems proposed by Carey (2009), Spelke (Spelke & Kinzler, 2007) and others, promote the existence of important, innate, core concepts. Whilst Carey supports evidence for the existence of innate representations that are not merely perceptual in character, she also proposes the development of more complex concepts and theories beyond this (which are not modular in nature). Both sides of this proposition are somewhat controversial, but it generates clear predictions. Core cognitive systems should be specifically limited in terms of the scope of information they can process, and should not vary through development, though general processing associated with it may do so. Like purely modular accounts of ToM a core cognition account allows for complex concepts being innate, but contrary to purely

modular accounts suggests that later development may be important. Such an account also differs crucially from most other accounts that afford for “learning” of conceptual information (Gopnik & Metlzoff, 1997; Perner, 1991) in suggesting that learning can be specific to a given domain. In Chapter 2 I will discuss a system for Level-1 perspective-taking as being *originally automatic*, which I believe to be consistent with a core cognitive apparatus for ToM.

1.3.3 Infant Behaviourists

Of course, there is an alternative to the conclusion that infants have the necessary conceptual apparatus to pass false belief tasks, if not the necessary executive capacity to express their knowledge. Perner and colleagues (Perner & Ruffman, 2005; Ruffman & Perner, 2005) have maintained that the recently found success of infants can be explained through their application of behavioural rules. Perner and Ruffman maintain that it is only at four that children have the appropriate domain general concepts to truly understand the minds of others.

1.3.3.1. Behavioural rules

The suggestion that behavioural rules can allow for seemingly impressive performance has been made for both infants and non-human animals (Penn & Povinelli, 2007; Perner & Ruffman, 2005; Ruffman & Perner, 2005). The idea of such accounts is that by tracking regularities in the behaviour of agents we can achieve something that looks a lot like ToM, but really does not require any ascription of anything that might be considered a mental state. For example, one might solve a false belief task not by imputing and using Maxi’s *belief that* the chocolates are in the drawer, but rather by having a rule that people normally look for things *where they*

saw them last. Perner and Ruffman propose that such behavioural rules may provide for some success in conventional situations, but should later be reinterpreted in terms of mental states to provide for extra flexibility. For example, if we always reason that people will look where they last saw things, our judgements will at times be incorrect for they don't always do so. People may wish to avoid an undesirable item, or lead someone else away from a favoured item. Of course, even more complicated series like these may also be attributable to more complex behavioural associations (Epstein, Kirshnit, Lanza & Rubin, 1984; Sobel & Kirkham, 2007). Behavioural rules are a possible route to efficiency, and plausibly even some degree of flexibility, however, proponents of this view must find evidence to address two related issues (Apperly & Butterfill, 2009). Firstly, it is crucial that such behavioural rules that are complex enough to support the relevant inferences are truly evident in agents' behaviours. Following this, it is equally important to show that we are capable of, efficiently, recognising such patterns. For the purposes of this thesis, I will take it as sufficient to say that such a route to efficiency *is* plausible (even in infants), and also suggest that if such behavioural rules really do provide for explanation of how we solve some ToM problems, this does not make such a solution any less interesting or informative (Shettleworth, 2010). Importantly, if behavioural rules are responsible for success on indirect measures of ToM, then explanations of the shift in performance on direct measures (section 1.1.7-1.1.9) become more important (and it is unlikely that this shift is purely the result of improvements in general performance).

1.3.4 Implicit Theory of Mind

Even before the recent studies showing success by infants on False Belief-like tasks, there was some debate about whether traditional False Belief tasks were really the

best way to test ToM abilities (Bloom & German, 2000; Leslie, 1994). Whilst there are good reasons to believe that standard False Belief tasks may not capture all the competencies of young children, it is worth highlighting the remarkably consistent finding that children fail these seemingly simple tasks, in many different forms up to the age of four (Hogrefe et al., 1986; Wimmer & Perner, 1983; Wellman et al., 2001). In other words, there is the big question to answer of why children still fail tasks at the age of 3 if they have been able to solve these tasks since the age of 15-months (or even 7 months, Kovacs et al., 2010). One response to this is to suggest that measures involving eye gaze are more sensitive “implicit” measures, whilst “explicit” measures inherently require more executive resources (Baillargeon, Scott & He, 2010).

The idea that explicit and implicit tasks may allow children to show different abilities is not a new response to the recent work, in fact Clements and Perner (1993), suggested the very same distinction to explain the lack of relationship between 3-year olds’ first eye movements and their explicit responses in false belief tasks. Clements and Perner (1993) propose that “implicit” knowledge of false beliefs may precede “explicit” false belief understanding, suggesting that each portrays a different “type of knowledge” (Clements & Perner, 1993, p391). Specifically, Clements and Perner tentatively propose that gaining knowledge about a fact may be very different from making a judgment about a fact. This is a very different suggestion to that made by Baillargeon et al (2010), in that here an implicit knowledge is thought to be qualitatively different from mature ToM. Both descriptions of implicit theory of mind directly address the surprising differences in performance on different tasks. However, descriptions of implicit and explicit ToM seem to provide little extra explanation of the findings, as what makes a response “explicit” or “implicit” remains

somewhat ill-defined. This is also a particular problem if one supports a notion that early ToM abilities are the basis of later ToM performance.

1.3.5 Two Systems for ToM

It may seem that both broad kinds of account discussed so far have similarities, in allowing for infants achieving impressive, efficient performance, but accepting that infants may not have a fully fledged ToM. The key difference, of course, lies in the fact that those who propose a purely modular/innate ToM (Leslie, 1993; Onishi & Baillargeon, 2005) suggest that infants have all the conceptual abilities to process others' mental states, but not necessarily all the general knowledge or processing power. On the other hand, those who propose infants' success can be explained by behavioural rules (Perner & Ruffman, 2005; Ruffman & Perner, 2005) suggest that only later children develop fully fledged conceptual apparatus. A third plausible alternative is that infants' understanding is neither a pre-cursor to later abilities, nor a fully-fledged ToM, but rather that it represents just one independent system for ToM.

That humans may have two systems for ToM has recently been suggested by Apperly and Butterfill (2009) as a potential solution to the conflicting demands placed by different tests of everyday ToM. If, on the one hand, we need our ToM to be fast and efficient, then we might expect such a system to have certain kinds of cognitive features (perhaps similar to those of Leslie's ToMM). On the other hand if ToM needs to be flexible, accurate and controlled, we should expect it to have a whole other set of features (perhaps similar to Perner's explicit ToM; Clements & Perner, 1993, or the domain general ability to metarepresent, Leekam et al., 2009; Perner, 1991). One way of solving this apparent contradiction is by suggesting that these distinct processes are

completed by entirely separate systems. This is a solution which has been used to solve similar problems in other areas of cognition, such as number cognition (Feigenson et al., 2004) and general reasoning (Evans, 2003). In number cognition multiple systems allow for success in different numerical problems (Feigenson et al., 2004). On the one hand, fast and efficient systems, which are present in infancy and in some non-human animals, allow for computation of precise small numerosities and large ratios. On the other hand, a system of reasoning gained through experience and formal instruction allows for computation of problems involving complex concepts and processes such as imaginary numbers, vector spaces and infinite sets with finite sums. Apperly and Butterfill (2009) draw a comparison with the competing demands made by tests of number cognition and ToM and suggest that a parallel solution could be found.

1.3.5.1 Limits

In number cognition, signature limits provide crucial converging evidence for the presence of multiple systems (Feigenson et al., 2004; Spelke, 1991; Spelke & Kinzler 2007). Signature limits are specific constraints on the information a system can process. For example, infants, some non-human animals and adults under time pressure are thought to use a low-level system for calculating numerosity, but in all cases this system cannot calculate numbers greater than 4. In other words, the number 4, whilst only differing from other numbers in an arbitrary manner, defines a limit on this system. That this is the case across different participant groups in very different tasks, suggests that this is a single system prevalent across these different groups.

Apperly and Butterfill (2009) suggest that identification of signature limits is something we should expect if ToM is really achieved by multiple systems. Different performance under different conditions does not necessitate the involvement of distinct systems, as a single system could perform differently in different circumstances (or at different stages of development). Evidence of consistent, and seemingly arbitrary, limits at different stages of development (either ontogenetic or phylogenetic) does suggest evidence for a specific, bounded, system. If this system is limited it also implies another, more flexible system. A flexible system for ToM should primarily be limited by the demands it places on general processing resources, and by the fact that sometimes individuals do not have all the information they need to make accurate ToM judgements. It should also, of course, be limited in what it can achieve in a given time limit, or under dual task conditions. An efficient system on the other hand need not necessarily be limited by time pressure or dual task conditions. However, we should expect such a system to have strict limits to the flexibility of its performance. An efficient system for ToM should be efficient through some form of encapsulation, so should only operate on very specific information under very specific constraints. Thus signature limits are the central piece of evidence for just such a system. In the current thesis, chapters 3 and 4 examine whether the Level-1/Level-2 distinction on visual perspective-taking may be a limit on efficient ToM. I will propose that evidence that this is the case suggests that a low-level, but strictly limited, system may be responsible for success of infants and non-human adults in tasks one might predict to require complex resources for executive functions and language.

1.3.6 Summary

How to resolve the competing demands for efficiency and flexibility on cognitive systems for ToM must be addressed in any comprehensive theory of ToM. It should hopefully be apparent that different cognitive systems for ToM may reflect features of more than one of the theories proposed in this section. That infants and non-human animals can achieve success on tasks traditionally assumed to involve imputing mental states highlights that such tasks can be passed successfully with efficient processing. The key to explaining such processing involves explaining how such efficient processing can be achieved. I have suggested that behavioural rules and distinct, encapsulated, but limited systems (or modules) may be plausible solutions to this. In the earlier discussion (Section 1.2) I also suggested the possibility of automatization as a route by which processes could become efficient. I wholly endorse (and consider no contradiction in) the possibility that all of these options may be in part responsible. The experiments in Chapters 2-4 provide relevant information to how we should address this question. By looking at efficient perspective-taking in children and adults these experiments examine the plausibility, and scope, of a low-level, and distinct system that may be responsible for some aspects of ToM. Chapter 6 on the other hand, investigates a specific, yet related, aspect of cognition, that of spatial perspective-taking. To highlight the link to this perspective, it is first of all important to define what we mean by a perspective at all.

1.4 Different kinds of perspective-taking; representational format and requisite cues

In Chapter 3 of this thesis, I consider two dimensions along which perspectives can be distinguished: the nature of the types of content involved (Sparse vs. Rich) and the

nature of the association required between a perspective and an individual (Subject-dependent vs. Subject-independent). A subject-dependent perspective may require a specific history or belief: for example in a false belief task, Maxi only believes the cupboard to be empty because of his past experience, not because of his current, perceptual position in the world. A subject-independent perspective, on the other hand, may only require an individual to be in a specific place at a specific time: for example it may be that from where you are stood you can see object A, but not object B, but this would also be the case for any other person with normal vision. In Chapter 3 I suggest that such dimensions upon which representational format can be distinguished may prove informative in describing absolute, signature limits to efficient processing. There is also the quite separate issue of what the everyday cues to such processing are. Some kinds of perspective-taking do not necessarily require a subject at all, be it dependent or independent. Spatial perspective-taking (Kessler & Thomson, 2009; Michelon & Zacks, 2005), normally refers to the relationship between agents and objects, but actually requires merely an object that is directed. In Chapter 6 we investigate whether perspectives generated by a social agent differ from perspectives generated by a fronted object.

1.5 Frames of Reference and Spatial Perspective-taking

In Chapter 6 I concentrate on the notion of a Frame of Reference, which allows for the direct manipulation of whether a perspective is generated by an agent or an object. Frames of reference provide an internal representation of space upon which a linguistic utterance can be mapped (Carlson-Radvansky & Irwin, 1993). Without such frames of reference, we cannot understand how statements refer to the relative positions of people and objects. Such questions have been of great interest to those

specifically interested in spatial cognition (Carlson-Radvansky & Irwin, 1993) and in the relationship between language and cognition (Levinson, 1996). Surprisingly, though, there has been little focus on the clear links between these kinds of judgments and judgments of psychological perspective. This will be discussed in greater detail in the chapter itself, but it is worth noting at this stage some key comparisons. Firstly, there is a superficial similarity in how these judgements are made. One has to identify features of an individual or object and use them to determine a relationship between this subject/object and others in the scene. Secondly, it is known that some of the same resources are recruited in each process, such as inhibition (Carlson-Radvansky & Jiang, 1999; Qureshi, Samson & Apperly., 2010). Also, and perhaps most importantly, both psychological and spatial perspective-taking judgements require resolving a potential conflict between the position of self and other within a scene.

The other reason for being particularly interested in the case of frame of reference judgements which involve psychological perspectives is as a case study of how effortful, controlled processing and involuntary or efficient processing of an individual's perspective interact. Specifically, in everyday calculation of such decisions, is a subject with a perspective treated in any way differently from an object with merely a frame of reference?

1.6 *Summary*

There is no doubt that recent findings showing success in ToM by infants (Onishi & Baillargeon, 2005) and non-human animals (Clayton & Emery, 2003) have provided a key new empirical foundation which must be explained in any theory of ToM. I am equally confident that recent findings from adults (Apperly et al., in press; Keysar et

al., 2003; Samson et al., 2010) should also be considered in any comprehensive account of ToM. The empirical investigations on which this thesis is founded are organised with both these beliefs in mind. I am not naive enough to believe that the following chapters will bring a complete picture of the role of controlled and efficient processing of ToM, but propose that each of the experiments detailed begins to address some of the problems posed by apparent contradictions between findings from infants, children, non-human animals and adults. All of the experiments detailed herein have participant groups aged between 6-years and adulthood. Even prior to testing, I broadly assumed that all the participants I have tested would be able to pass all the tests I have administered, given enough time and information. Whilst this might seem an unusual approach to developmental psychology, I hope, in the end, it will be shown to be a critical and necessary one. At several points in the upcoming chapters I will appeal to the notion of convergence; that is that findings across numerous tasks, age-groups and species will in the end provide us with something approaching a complete picture of ToM. There is, of course, something rather unsatisfactory about this. It is certainly counter-intuitive to explain infants' success through studying the performance of adults, particularly when we know infants fail tasks that adults pass. I believe, though, in many ways that solutions gained in this way are necessary, for it is only with a complete picture of what ToM is that we can explain its development, in ontogeny and phylogeny. Conversely, I also believe that findings from infants and non-human animals will help structure our beliefs of what a mature ToM should look like. In particular, evidence that ToM can be achieved efficiently surely impacts on what we should expect to see in adults' performance.

Samson et al. (2010) found adults to compute perspectives in a somewhat automatic way. Chapter 2 investigates whether the findings from Samson et al. (2010) generalise to children. The three experiments in Chapters 3 and 4 focus on whether the Level-1/Level-2 distinction provides a limit to efficient ToM. This really hopes to answer two questions. Whether there are limits to efficient ToM, and if so, what are they? If there are limits to efficient ToM this suggests that at least one mechanism for efficient ToM is of the type of *core cognition* suggested by Carey and colleagues (or low-level *system* proposed by Apperly & Butterfill; 2008). Precisely what this limit is, whilst providing clarity and comprehensiveness, remains relatively theory neutral. Chapter 5 investigates links between executive functions and a range of ToM abilities in middle childhood. I propose that if we are to investigate a ToM that improves from infancy to adulthood, we must also investigate what underlies this improvement. Chapter 6 investigates perspective processing in the light of different cues, specifically through looking at the impact of psychological perspective on judgements of spatial relations. As part of this overall thesis, I suggest that we must clarify and broaden our notion of perspective as there seem to be clear similarities between perspectives generated by both agents and fronted objects.

CHAPTER 2

Egocentrism and automatic perspective-taking in children and adults

This chapter, largely in its current form, has been accepted for publication as the
article:

Surtees, A. D. R. & Apperly, I.A. (in press), Egocentrism and automatic perspective-taking in children and adults. *Child Development*.

2.0 Abstract

Children (aged 6-10) and adults completed a novel visual perspective-taking task that allowed quantitative comparisons across age groups. All age groups found it harder to judge the other person's perspective when it differed from their own. This egocentric interference did not decrease with age, even though, overall, performance improved. In addition, it was more difficult to judge one's own perspective when it differed from that of the other person, suggesting that the other's perspective was processed even though it interfered with self perspective judgments. In a logically equivalent, non-social task, the same degree of interference was not observed. These findings are discussed in relation to recent findings suggesting precocious Theory of Mind abilities in infancy.

2.1 Introduction

Piaget and Inhelder (1956) suggested that children as old as 7 years found it difficult to judge how a 3-dimensional model of three mountains would appear to someone who viewed it from a different angle. Since this classic work there has been a steady downward trend in the age at which children have been shown to have such abilities. Researchers in the 1980s found success on conceptually similar problems in children aged 4 to 5 years (Flavell, Everett, Croft & Flavell, 1981; Light & Nix, 1983). Recently, success has been reported on very simple tasks in children as young as 2 years (Moll & Tomasello, 2006), and perhaps even younger infants (Sodian, Thoermer & Metz, 2007; Song & Baillargeon, 2008). In contrast, we know little about development once children first pass these tasks. This oversight leaves us ignorant about the cognitive characteristics of perspective-taking, and whether these change as

children gain practice and cognitive resources. We developed a novel task to examine simple perspective-taking in children aged from 6 to 10 years and adults.

2.1.1 Egocentrism (interference from self-perspective)

A recurrent characteristic in young children's explicit perspective-taking judgments is egocentrism: children's errors show a systematic bias towards the child's own point of view (Fishbein, Lewis, & Keiffer, 1972; Flavell et al., 1981; Liben, 1978; Piaget & Inhelder, 1956). Egocentric interference from self-perspective is also observed when older children and adults perform perspective-taking tasks that are more complex, or that require judgments of certainty about what someone else will do or think, with some evidence suggesting that this egocentrism decreases with age (e.g., Bernstein, Atance, Loftus, & Meltzoff, 2004; Birch & Bloom, 2007; Epley et al., 2004; Keysar, Lin & Barr, 2003; Nickerson, 1999; Royzman, Cassidy & Baron, 2003). However, although at a general level "egocentrism" may be a recurrent feature of perspective-taking, no study has demonstrated egocentrism in older children and adults on tasks equivalent to those used with young children. Thus, in the current work we tested the degree of egocentrism in children and adults on a "Level-1" perspective-taking task that required judgments that are logically equivalent to those required in tests used with children aged 2 and younger (e.g., Flavell et al., 1981).

2.1.2 A visual-perspective-taking task for adults

Samson, Apperly, Braithwaite, Andrews & Bodley-Scott (2010; Wang, Apperly, Samson & Braithwaite, under revision) used a computer-based task in which adult participants made time-pressured judgments about the number of dots seen by a cartoon character on the walls of a room. Sometimes the cartoon character saw

exactly the same number of dots as the participant, and sometimes s/he saw fewer. This is a Level-1 perspective-taking task because it requires judgments about *what* someone sees, whereas a Level-2 perspective-taking task requires judgments about *the particular way* in which they see something (Flavell et al. 1981). When they judged the character's perspective, participants were slower and more error-prone if they saw more dots than the character. This is evidence of egocentric bias because it shows that participants' own discrepant perspective interfered with judgments of the character's perspective. We adapted this task in order to compare the size of the egocentric effect observed in adults with the effect observed in children aged 6- to 10-years.

2.1.3 Automaticity

Although Samson et al. (2010) found that participants' own perspective interfered with their explicit judgments about the character's perspective, the same series of experiments provided evidence that the character's perspective itself was being calculated in a relatively automatic manner. One signature of an automatic process is that it may be executed even when this interferes with successful performance on some other task (Dijkerman & Smit, 2007; Kilner, Paulignon & Blakemore, 2003; Lefevre, Bisanz & Mrkonjic, 1988). To test for this, Samson et al's experiments also included "self" trials where participants judged how many dots they themselves could see on the wall of the room. The important finding was that these self-perspective judgments were slower and more error-prone when the character saw fewer dots than the participant. This effect indicated that even though the character's perspective was irrelevant and, in principle, could be ignored on Self-perspective trials, in fact the character's perspective was processed, and the content of this resulted in interference

when participants had to judge their own perspective. A further experiment in Samson et al.'s study found that this effect persisted even when participants only ever made judgments about their own perspective for the entire experiment. That is to say, participants appeared to be processing the character's perspective even when it is wholly irrelevant to the task at hand, and this interfered with participants' judgments about their own perspective when their own perspective was different from that of the character. To this extent, these data show evidence of automatic Level-1 perspective processing in adults.

2.1.4 Routes to automaticity

There are at least two ways in which adults might come to calculate other people's perspectives in an automatic manner. One possibility is that Level-1 perspective-taking is not initially automatic in children, but by adulthood repeated practice has resulted in automatization. If so then, on Samson et al.'s task, younger children should not process the character's perspective automatically and so should suffer less or even no interference from the character's perspective when they judge their own, self-perspective. Another possibility is that the automaticity observed in adults reflects the operation of a cognitively efficient process for simple perspective-taking that has been present since infancy. This possibility is consistent with evidence that infants and young children may show precocious sensitivity to the perspectives of others when tested indirectly (via looking times or eye movements) rather than when required to make an explicit judgment (e.g., Clements & Perner, 1994; Onishi & Baillargeon, 2006; Sodian et al., 2007; Song & Baillargeon, 2008; Southgate, Senju & Csibra, 2006). Such "original automaticity" predicts that the interference effects observed in adults by Samson et al. (2010) will be observed in children of all ages, if only

appropriate methods could be found to test for these effects. In the current study we sought to make some progress on this question in Experiment 1A by testing children as young as 6 years on a paradigm very similar to that used by Samson et al. In Experiment 1B we tested the whether similar effects would be observed in an analogous task that did not require perspective-taking.

2.2 *EXPERIMENT 1A*

2.2.1 Method

2.2.1.1 Overview

On every trial participants heard instructions and viewed a cartoon avatar standing in a cartoon room with dots on the wall (See Figure 2.1). On “Self” trials, participants judged the number of circles they could see on the walls of a room. On “Other” trials, participants judged how many circles could be seen by the cartoon avatar in the picture. On “Consistent” trials the avatar could see the same number of circles as the participant. On “Inconsistent” trials the avatar’s position in the room meant that s/he saw fewer circles. Although it would have been interesting to create a situation in which it was the avatar that saw the greater number of circles, the current paradigm would not permit such a scenario.

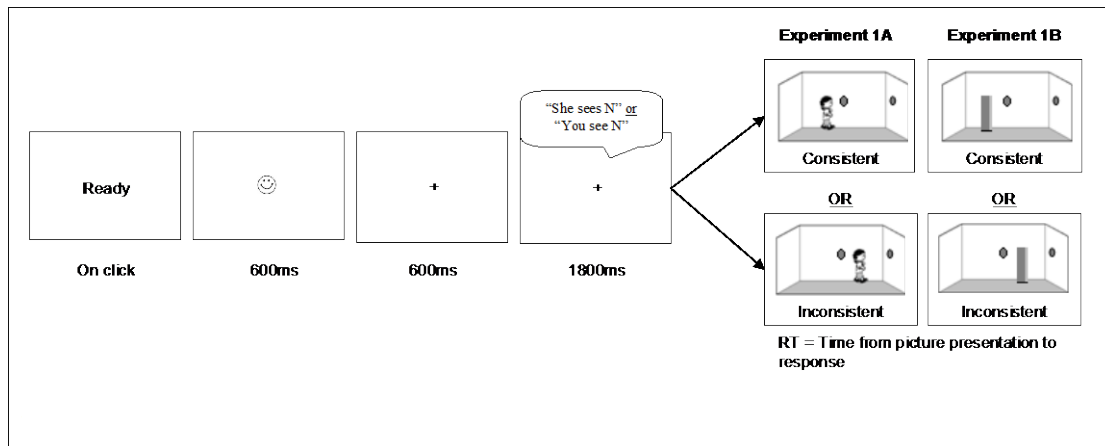


Figure 2.1. Schematic event sequence of experimental trials. Participants were cued as to the perspective they were to take and the number to verify. Following this they were presented with a picture stimulus. For Experiment 1B. “She sees N” was replaced by “Yellow-side N”.

2.2.1.2 Participants

Four groups of participants were tested: Undergraduates (N=11), mean age: 19.1 (range 18-23), 10 female; 10-year-olds (N=24), mean age 10.1 (range = 9:6-10:5), 13 female; 8-year-olds (N=35), mean age = age 8.3 years (range = 8:0-8:5), 18 female; 6-year olds (N=36), mean age = 6.4 (range 6:1-6:11), 20 female. Adult participants were recruited for course credits, and were predominantly white British. Child participants were recruited from 2 schools in a working-middle class area of Wolverhampton; as for adults, the majority of participants were white British.

2.2.1.3 Design and Procedure

Child participants completed the experiment in a room adjacent to their normal classroom. Adult participants completed the task in a testing cubicle. Instructions included a detailed description of the procedure and an instruction to respond as quickly and accurately as possible. Practice trials were completed until the participant

had successfully answered a question for each of the four conditions (Self-Consistent, Self-Inconsistent, Other-Consistent, Other-Inconsistent)

On each trial, participants viewed successive fixation stimuli (a smiling face (600ms) and a fixation cross (600ms)) followed by a 1800ms auditory stimulus (either “He sees N” or “You see N”, where N ranged from 1 to 3, so that the number of circles was within the range that could be enumerated quickly and accurately via subitization, Trick and Pylyshyn, 1994) and then the test picture depicting an avatar in a room with 1-3 dots on the wall. Participants pressed one of two colored keys to indicate whether or not the auditory stimulus correctly described the picture (on half of the trials, the auditory stimulus did match the picture, and on half it did not). Response time was measured from the onset of the picture. Participants completed four practice trials. Child participants completed 48 test trials: 24 where self and other perspectives were consistent (12 Self, 12 Other) and 24 where self and other perspectives were inconsistent (12 Self, 12 Other). Adults completed two cycles of the child experiment (96 trials). Self and Other trials were mixed within each block of trials. The experiment was presented using E-prime 2.0 (Psychology Software Tools, Inc.) on a laptop computer.

2.2.2 *Results*

Examining the effect of perspective consistency on Other trials allowed us to test for egocentric interference from self perspective when making explicit judgments about the avatar’s perspective. Examining the effect of perspective consistency on Self trials allowed us to test whether the avatar’s perspective was processed automatically, leading to interference with judgments about self perspective. Self and Other trials

were analysed separately as we had no hypotheses about the relative size of any effects observed in these two conditions. Following Samson et al. (2010) only trials where the auditory stimulus and the picture matched were used in the analysis. Mean Reaction Times and Error data for both experiments 1A and 1B are presented in Figure 2.2.

2.2.2.1 Other Trials

Response Times (RTs). Data that were two standard deviations from the mean were omitted from the analysis of RTs (3.6% of the data for 6-year olds, 2.9% for 8 year olds, 4.3% for 10-year-olds and 2.1% for adults), as were data from incorrect responses. Results were not affected by excluding using less strict criteria (outliers 2.5 or 3 standard deviations from the mean).

An ANOVA with Consistency as a within subjects factor, and Age as a between subjects factor revealed an effect of Age ($F(3, 105) = 59.20$; $p < .01$, $\eta^2 = .63$). T-tests showed that each older age group responded more quickly than the adjacent younger age group (lowest $t(58) = 6.16$; all $ps < .01$). There was a main effect of Consistency ($F(1,105) = 13.12$; $p < .01$, $\eta^2 = .11$; Consistent<Inconsistent), but no significant interaction between Age and Consistency $F(3, 105) = .14$; $p = .94$. Planned comparisons showed higher RTs for Inconsistent compared with Consistent trials for all age groups (lowest $t(34) = 2.06$, all $ps < .05$), see figure 2.2.

Errors. A similar ANOVA on errors showed no effect of Age ($F(3, 105) = .72$; $p = .54$). There was a main effect of Consistency ($F(1,105) = 7.55$; $p < .01$, $\eta^2 = .068$; Consistent<Inconsistent), but no significant interaction between Age and

Consistency $F(3, 105) = .52$; $p = .24$. Only 8-year-olds showed significantly more errors on Inconsistent trials than on Consistent trials ($t(34) = 2.78$, $p < .01$).

2.2.2.2 *Self Trials*

Response times (RTs). Outliers were excluded using the same criterion as in Other trials (1.7% of data for 6-year olds, 2.93% for 8 year olds, 3.9% for 10-year-olds and 1.7% for adults)

An ANOVA with Consistency as a within subjects factor, and Age as a between subjects factor revealed an effect of Age $F(3, 105) = 79.09$, $p < .01$, $\eta p^2 = .70$. T-tests showed that each older age group responded more quickly than the adjacent younger age group (lowest $t(34) = 5.90$; all $ps < .01$). There was a main effect of Consistency ($F(1, 105) = 32.45$, $p < .01$, $\eta p^2 = .24$; Consistent<Inconsistent), but no significant interaction between Age and Consistency $F(3, 105) = 2.34$, $p = .24$. Planned comparisons showed higher RTs for Inconsistent compared with Consistent trials for all age groups (lowest $t(23) = 2.45$, all $ps < .05$)

Errors. A similar ANOVA on errors showed a marginal effect of Age ($F(3, 105) = 2.62$, $p = .054$), an effect of Consistency ($F(1, 105) = 7.28$, $p < .01$, $\eta p^2 = .066$; Consistent<Inconsistent) and a significant interaction between Age and Consistency ($F(3, 105) = 4.81$, $p < .01$, $\eta p^2 = .12$). 6-year olds, 8-year olds, and adults showed significantly more errors on Inconsistent trials than on Consistent trials (lowest $t(34) = 3.18$, all $ps < .01$).

2.2.3 Summary of Experiment 1A

Experiment 1A clearly showed that participants were processing both perspectives, even when it was not necessary for the task and, in cases where perspectives were inconsistent, when it actively hindered performance. However, using a mixed-block design, it is possible that the interference caused was due to executive demands on task-switching, or due to participants adopting a strategy that took into account both possible options for each trial. Experiment 1B addressed this with a task that matched the one used in Experiment 1A in terms of the possibility of task switching costs or the adoption of strategies, but which did not entail perspective-taking.

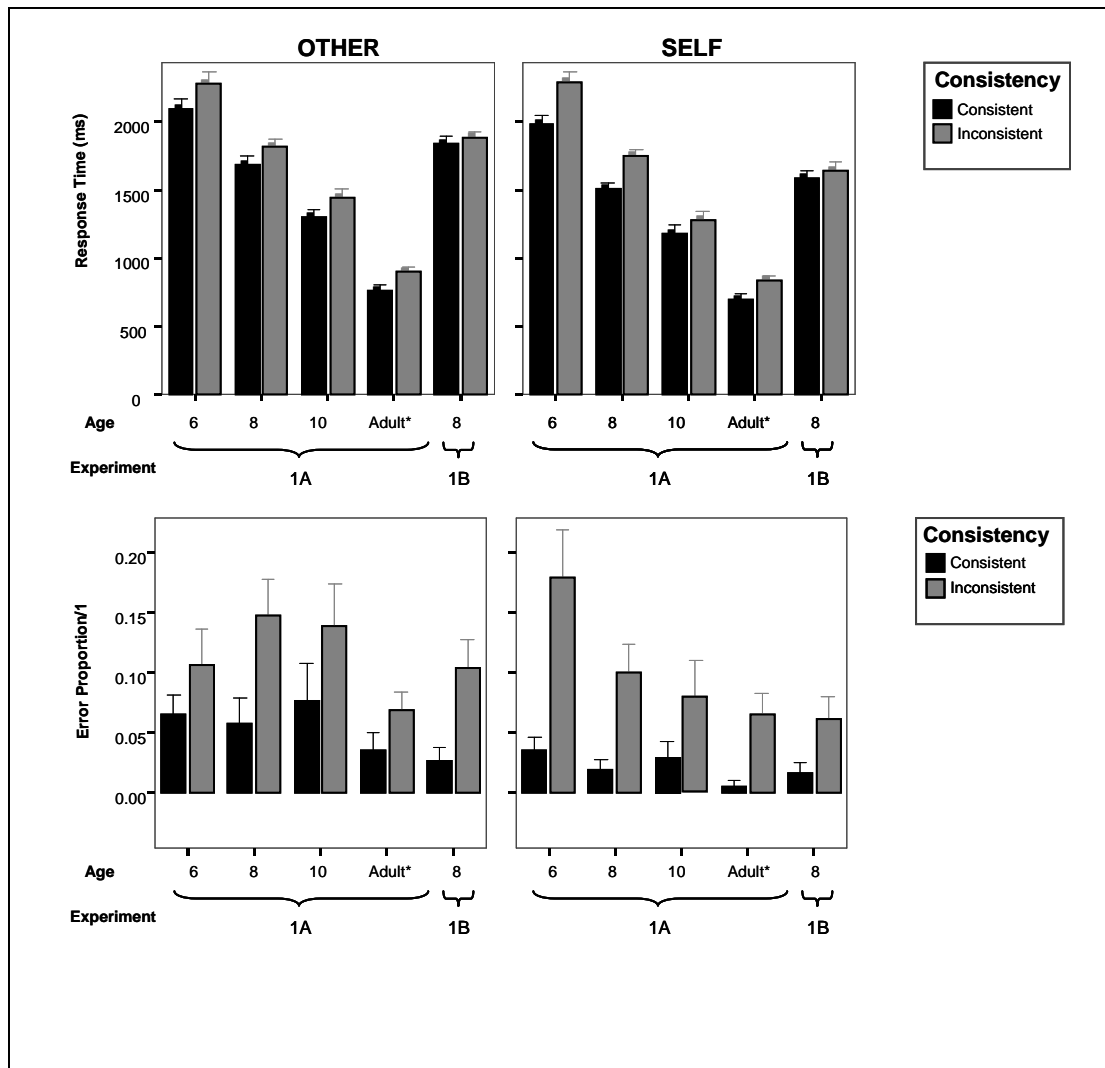


Figure 2.2. Mean Response Times and Error Proportions for children and adults in experiments 1A and 1B (Bars indicate standard error of the mean).

2.3 EXPERIMENT 1B

To test the specificity of the effects found in Experiment 1A to the social domain, we tested a further sample of 8-year-old children using non-social stimuli. Only one age group was tested as all age groups had shown qualitatively similar performance in Experiment 1A. Eight year olds were selected as they formed the mid-point of our child age-group.

2.3.1 Method

2.3.1.1 Participants

In Experiment 1B 30 participants (Mean age = 8.2; Range 8:0-8:5, 18 female) were tested. Participants were recruited from a school in a working-middle class area of Wolverhampton; the majority of participants were white British.

2.3.1.2 Design and Procedure

Experiment 1B was identical to Experiment 1A except that a bi-color stick replaced the cartoon child, and the verbal cue “yellow side N” replaced the verbal cue “s/he sees N”. Participants judged whether the number, N, was correct for the number of circles on the yellow side of the stick. Thus, the task was structurally similar to that in Experiment 1A, but had no social stimulus.

2.3.2 Results

For each analysis we conducted a t-test to compare Consistent and Inconsistent trials for Experiment 1B, followed by a 2(Consistency) by 2(Experiment) ANOVA to compare results from Experiment 1B with results from the 8-year-olds in Experiment 1A. The t-tests evaluate the effects found specifically in Experiment 1B, whilst the ANOVAs test whether the patterns observed in Experiment 1A with social stimuli were significantly different from those observed in Experiment 1B with non-social stimuli.

2.3.2.1 Stick / Other trials

Response times. Outliers (3.2% of the data set) were removed using the same criterion as in Experiment 1A. The trend for an effect of Consistency in Experiment 1B was not significant, ($t(1, 29) = .80, p = .43$). However, the results of Experiment 1B and 1A did not differ statistically: the ANOVA showed no effect of Experiment ($F(1, 66) = 2.54, p = .17$, a main effect of Consistency ($F(1, 66) = 4.21, p < .05, \eta p^2 = .062$) and no interaction between Experiment and Consistency: $F(1, 66) = 1.04, p = .63$.

Errors. In Experiment 1B there were more errors on Inconsistent than Consistent trials ($t(1, 30) = 3.01, p < .01$). The results of Experiment 1B and 1A did not differ statistically: the ANOVA showed no main effect of Experiment ($F(1, 64) = 2.28, p = .14$) a main effect of Consistency ($F(1, 64) = 15.78, p < .01, \eta p^2 = .20$), and no significant interaction between Experiment and Consistency $F(1, 64) = .11, p = .78$.

2.3.2.2 Self Trials

Response times. 3.3% of the data points were removed as outliers. Within Experiment 1B, there was no significant effect of Consistency on RT ($t(29) = 1.09, p = .28$). Importantly, this pattern differed significantly from that observed in Experiment 1A. The ANOVA revealed no effect of Experiment ($F(1, 64) = .12, p = .74$), an effect of Consistency ($F(1, 64) = 18.73, p < .01, \eta p^2 = .23$), and a significant interaction between Experiment and Consistency ($F(1, 64) = 7.09, p < .01, \eta p^2 = .10$), reflecting the significant effect of Consistency in Experiment 1A, and the absence of this effect in Experiment 1B.

Errors. Within Experiment 1B responses on Consistent trials were more accurate than on inconsistent trials ($t(29) = 2.17, p < .05$). Results from Experiment 1A and 1B did not differ statistically. The ANOVA showed no effect of Experiment ($F(1, 64) = 1.58, p = .21$) an effect of Consistency ($F(1, 64) = 14.25, p < .01, \eta^2 = .18$), and no interaction between Experiment and Consistency ($F(1, 64) = 1.10, p = .30$), though the numerical trend was for a larger effect of Consistency in Experiment 1A.

2.3.2.3 Summary of Experiment 1B

In summary, children's judgments about the number of circles on the yellow side of the stick in Experiment 1B did not differ in speed or accuracy from their judgments about the number of circles seen by the cartoon child in Experiment 1A. This is consistent with other observations that egocentric effects in social perspective-taking are also apparent in well-matched non-social tasks (e.g., Perner & Leekam, 2008). It seems as if merely having your own perspective is enough to interfere with a range of tasks that require this perspective to be set aside, regardless of whether they require perspective-taking. Critically, however, the speed of children's judgments about the number of circles *they* saw differed across the two experiments. In Experiment 1A children were slower to judge how many circles they saw when the cartoon child saw fewer than them, whereas in Experiment 1B the same judgments were not slowed by the presence of fewer circles on the yellow side of the stick. This difference makes it unlikely that participants' slow judgments about Self perspective on Inconsistent trials in Experiment 1A were due to unintended features of the task or stimuli. For example, unintended causes of the effect observed in Experiment 1A might have come from the fact that children were required to switch between self judgments on some trials and

other judgments on other trials, or that in Self-Inconsistent trials the group of dots that children had to judge was disrupted by the presence of the avatar. However, Experiment 1B also required task switching, and the group of dots that children had to judge on Self-Inconsistent trials was disrupted by the stick, yet the pattern observed on Self trials was different in Experiments 1A and 1B. Following Samson et al. (2010), who also compared similar avatar and stick conditions, we suppose that this difference is due to participants automatically processing the avatar's perspective in Experiment 1A, which results in interference when they must judge their own perspective. In contrast they did not automatically process the number of dots on the yellow side of the stick in Experiment 1B.

As a control condition, this still leaves open questions about the operation of automatic perspective-taking. The stick stimulus matched the avatar in terms of its overall dimensions and its placement in the room, but it remains an interesting question for future work what features of the avatar drive the automatic processing of its perspective. For example, it might be that these effects are dependent on the visibility of the eyes, or that they are equally strong when participants can only see the orientation of the avatar's body but not their eyes. Likewise, although we have evidence that simple perspective-taking is rather resistant to opportunities for top-down control it would be interesting to know whether any kind of top-down control was possible. For example, Teufel, Alexis, Todd, Lawrance-Owen, Clayton and Davis (2009) have recently shown that apparently automatic following of eye gaze can be moderated if participants believe that the person whose eye gaze they observe cannot actually see. It is possible that the current phenomenon of "automatic" perspective-taking might be influenced by such socially relevant knowledge. But neither finding

would undermine the basic conclusions from the current study, that there is a relatively automatic process of perspective-taking (observed in the Self condition of Experiment 1A) that is not an artefact of the task that we used.

2.4 Discussion

We measured the speed and accuracy of self- and other-perspective-taking of adults and children on a very simple visual perspective-taking task logically equivalent to those passed by children aged 2-years or younger. At all ages we found evidence of egocentrism, and of the opposite effect of interference from the other's perspective when judging self-perspective.

2.4.1 Egocentrism

Egocentric errors – by which we mean errors that show an influence of one's own privileged perspective – are common when young children perform simple perspective-taking tasks, and egocentric bias is common when adults complete more complex tasks (Bernstein et al., 2004). The current study is the first to show that the egocentrism observed in young children's errors on the very simplest (Level-1) visual perspective-taking tasks is also apparent in errors and response times throughout development into adulthood. This suggests that egocentrism in adults does not merely resemble egocentric phenomena observed in children but, for simple perspective-taking at least, reflects the same underlying cognitive processes: we cannot help having our own perspective and this interferes with judgments about the perspective of others. Interestingly, although there was age-related improvement in general speed and accuracy of perspective-taking, there was no reduction in the size of the egocentric effect, as demonstrated by the absence of an interaction between age and

perspective-consistency. This suggests that age-related increases in general processing resources such as inhibitory control may improve the efficiency of perspective-taking, but not by reducing egocentrism. We remain relatively neutral as to the nature of the egocentrism operating here. On the one hand it is clear that this interference is from a self-view, but in all our trials the self-view of the scene may also be considered (in Light and Nix's, 1983, terms) a "good view". There is potential for further investigation of this by degrading self-perspective, and so generating a self-view that is not a "good view".

2.4.2 *Automatization or original automaticity?*

Consistent with Samson et al. (2010) we found that participants' judgments about their own perspective were slower and more error-prone when the character in the room had a different perspective. Importantly, the same degree of interference was not observed in Experiment 1B, where children performed a structurally similar task with non-social stimuli. These effects can be explained if we suppose that in Experiment 1A children and adults calculated the number of dots that the character could see even when they were not told to, but did not perform the equivalent calculation of the number of discs on the yellow side of the stick in Experiment 1B. That is to say, the data indicate a relatively automatic process of Level-1 perspective calculation in children as well as in adults.

The absence of an age-related change in the size of the interference effect from the character's perspective suggests that automatic perspective-taking is not altered by increasing practice or availability of cognitive resources, at least in children over the age of 6. That is to say, the current study found no evidence that adults' automatic

perspective calculation is the result of automatization. However, we cannot rule out the possibility that children have already fully automatized the calculation of simple visual perspectives by the age of 6. It is quite possible that children have had enough exposure to social stimuli to have automatised the process of perspective-taking. Pilot work suggested that the current methods were unsuitable for younger children, but testing for similar interference effects between self and other in younger children's self-perspective-taking is an important avenue for future investigation.

Although the current data do not rule out automatization, they are clearly compatible with the alternative “original automaticity” hypothesis, whereby children and adults have a cognitively efficient ability for simple perspective-taking that is already present in infants. This view gains plausibility from the growing body of evidence that infants and young children show sensitivity to simple perspectives when these abilities are tested indirectly via looking times, eye movements or spontaneous actions (e.g., Clements & Perner, 1994; Onishi & Baillargeon, 2006; Sodian et al., 2007; Song & Baillargeon, 2008; Southgate et al. 2006). And indeed, the current findings may give insight into why infants and young children fail on more traditional explicit tests of the same abilities. Our findings suggest that information about what an agent sees may be automatically calculated (resulting in Self-Other interference on Self trials) but that making explicit judgments about what the agent sees opens the door to egocentric interference (resulting in Self-Other interference on Other trials). We suggest that adults and older children have the executive resources necessary to resist such egocentric interference, and so their explicit judgments are merely slower when self and other perspectives are in conflict. Infants and young children may lack such

executive resources, and so their explicit judgments are dominated by their own perspective (see e.g., Leslie, 1987; 2005; Friedman & Leslie, 2005).

This clearly raises the question of why explicit judgments require additional cognitive resources, and what purpose such explicit judgments might serve if information about other people's perspectives is already being calculated automatically. One hypothesis is proposed by Apperly and Butterfill (2009) who suppose that any capacities for automatic processing of visual perspective (or, for that matter, other mental states such as beliefs) will be limited to relatively simple cases. As one example of such a limitation Apperly and Butterfill (2009) suggest that Level-1 perspective taking may be automatic whereas Level-2 perspective taking may not be. On this account, explicit judgments recruit more general reasoning processes, which carry the cost of demands on memory and executive control, but bring the benefit of more flexible perspective-taking. Whether or not this particular hypothesis is correct, it is a priority for future work to investigate the role and scope of automatic versus controlled processes in making judgments about the perspectives of others.

2.5 Summary and link to Chapter 3

In Chapter 2, we showed that efficient visual perspective-taking was not limited to highly practiced adult perspective-takers. We suggested two alternatives as to what these findings mean. Firstly, that visual perspective-taking may be *originally automatic*: that is to say that efficient perspective-taking of this kind may be in place innately and allow for success by infants in such tasks (Luo & Baillargeon, 2007). The other alternative we proposed was that perspective-taking may be *automatised*, even by the age of six. One reason to think that this was not the case was the lack of developmental trend after the age of six: one might expect this automatic process to become more ingrained even after it first becomes automatic, or expect adults to be more successful at ignoring it when taking their own perspective.

The two explanations for the automaticity of perspective-taking in 6-year olds lead to very different predictions. If perspective-taking is originally automatic, one would predict it to have the same constraints in both infants and adults. If perspective-taking is automatised, one would expect any similar process to become automatic with equivalent experience. Chapter 3 evaluates both of these predictions by testing Level-2 perspective-taking in both children and adults. As yet there is no proof that children under the age of four can succeed on Level-2 perspective-taking tasks. If Level-1 perspective-taking is originally automatic, we should predict that Level-2 perspective-taking will not be automatic, even in adults. If Level-1 perspective-taking were automatised by the age of 6, we should expect Level-2 perspective-taking to be automatic, at least by adulthood.

CHAPTER 3

Direct and indirect measures of Level-2 perspective-taking in children and adults

This chapter, largely in its current form, has been submitted as the article

Surtees, A. D. R., Butterfill, S. & Apperly I., A. (submitted): Direct and Indirect
measures of Level-2 Perspective-taking in Children and Adults

3.0 *Abstract*

Studies with infants show divergence between performance on theory of mind tasks depending on whether *direct* or *indirect* measures are used. It has been suggested that direct measures assess a flexible but cognitively demanding ability to reason about the minds of others, whereas indirect measures assess distinct processes which afford more efficient but less flexible theory of mind abilities (Apperly & Butterfill, 2009). This leads to the prediction that performance on indirect measures should be subject to *signature limits*. The current study tested whether the Level-1/Level-2 distinction might constitute one such limit. The study adapted a task that has shown evidence of Level-1 perspective-taking on both direct and indirect measures (Samson et al., 2010). The aim was to test Level-2 perspective-taking in a sample of 6- to 11-year-olds (N=80) and adults (N=20). Participants were able to make Level-2 judgements on the direct measure, but did show egocentric interference. In contrast with the findings from Level-1 perspective-taking, there was no evidence of automatic processing of Level-2 perspectives on the indirect measure. This finding is consistent with the view that theory of mind abilities assessed by indirect measures are subject to inflexible limits. The Level-1/Level-2 distinction, suitably refined, marks one way in which efficient but inflexible theory of mind abilities are limited.

3.1 *Introduction*

Perspective-taking most commonly refers to being sensitive to another's mental states. These mental states can be beliefs, desires, intentions or perceptions. Another's non-mental states, such as being to the left or right of an object, are also sometimes considered within the notion.

Perspective-taking can enable successful social interactions, but effective participation in rapidly changing social situations often demands that perspective-taking is efficient, as well as accurate. Equally, keeping up with the complexity of some interactions calls for flexible perspective-taking. It is therefore pertinent to ask *how* competing demands for efficiency and flexibility are reconciled. In this paper we investigate one hypothesis: human adults and older children have multiple perspective-taking systems. One type of system is flexible but cognitively demanding. The other type trades flexibility for efficiency, and some of these efficient but less flexible systems (and only these) are also shared with infants, where they enable success on a variety of theory of mind tasks (see Apperly & Butterfill, 2009). If this hypothesis is correct it should be possible to find signature limits in efficient perspective-taking abilities in much the way that, in the case of numerical cognition, a four-item limit is a signature of a capacity for efficient tracking of numerosity (e.g., Feigenson, Dehane & Spelke, 2004). Note that this signature is observable both in infants and in adults. Here we examine whether the distinction between Level-1 and Level-2 perspective-taking is a signature limit on theory of mind. If so, we would expect to find that Level-1, but not Level-2, perspective-taking can be accomplished efficiently in older children and adults, and that Level-1 perspective-taking is an early development in infancy rather than being the product of later automatization.

While we suspect that the distinction between Level-1 and Level-2 perspective-taking may ultimately be too crude to fully isolate tasks that trade flexibility for efficiency (see discussion below), this is a well-established distinction which we can use as a first approximation to our view. The distinction between Level-1 and Level-2 perspective-taking has long been suggested by developmental researchers (Flavell,

Everret, Croft & Flavell, 1981; Flavell, Flavell, Green, Wilcox 1981; Lempers, Flavell, & Flavell, 1977; Masangkay, McCluskey, McIntyre, Sims-Knight, Vaughn & Flavell 1974). Level-1 perspective-taking requires the ability to understand that objects visible to oneself are not necessarily visible to another person (Flavell et al., 1981a). Flavell and colleagues defined Level-2 perspective-taking as understanding that “an object simultaneously visible to both the self and the other person may nonetheless give rise to different visual impressions or experiences in the two if their viewing circumstances differ” (Flavell et al. 1981a, p1).

There is now little debate that the Level-1/Level-2 distinction makes sense from a developmentalist’s perspective: it provides a satisfactory distinction between a set of tasks that seem to be passed prior to the age of four (Moll and Tomasello, 2005, Flavell et al., 1981a), characterised as Level-1, and those tasks which children younger than the age of four consistently seem to fail (Flavell et al., 1981a; Masangkay et al., 1974). Notably, while recent research has suggested that infants as young as 12.5 months may show evidence of Level-1 perspective-taking on indirect measures such as looking time (Sodian, Thoermer & Metz, 2007; Luo & Baillargeon, 2007), no such evidence has so far been forthcoming for Level-2 perspective-taking. Surprisingly though, there has been little effort to investigate why it might be that Level-2 tasks are more difficult than Level-1 tasks, or whether indirect measures of perspective-taking are anything other than more sensitive counterparts to traditional measures that ask for direct, explicit judgements. We next describe recent research on perspective-taking in adults, before going on to explore how such methods can be adapted to address these questions.

Two recent studies have examined adults' Level-1 perspective-taking using both direct and indirect measures. Samson et al. (Qureshi, Apperly & Samson, 2010; Samson, Apperly, Braithwaite, Andrews & Bodley-Scott, 2010) had adults complete a computerised task in which they viewed stimuli showing an avatar in a room. A number of red circles were located within the room, each of which was either visible to the avatar or not. On some trials ("Other" trials) participants were required to make a direct judgement about the avatar's perspective. Findings from this, direct, measure of perspective-taking converged with longstanding evidence of egocentric interference on perspective-taking found in children (Flavell et al., 1981a; Piaget & Inhelder, 1956): participants found it harder to judge another's perspective when it differed from their own. Moreover, this egocentric interference was increased when participants simultaneously performed a task that taxed executive function (Qureshi et al., 2010). These findings are consistent with the view that adopting others' perspectives remains cognitively effortful, even for adults (Epley, Keysar, Van Boven & Gilovich, 2004; Epley, Morewedge & Keysar, 2004).

The indirect test of perspective-taking came from "Self" trials, on which participants simply reported their own perspective in the presence of an avatar. On these trials, adults were slower and more error-prone in judging their own perspective when the avatar happened to have a different perspective than when his perspective was the same as theirs. This was an indirect measure of perspective-taking because there was no requirement that the participant should take the avatar's perspective, yet interference from the avatar's perspective when participants judged their own "Self" perspective suggests that they were processing his perspective nevertheless. Evidence from this indirect measure suggests that Level-1 perspectives are processed

automatically, in the sense that this processing occurred even when it was unnecessary and even when it hindered performance on participants' main task. Moreover, in contrast to findings from the direct measure, Qureshi et al. (2010) found that this automatic processing of Level-1 perspectives was not disrupted when adults simultaneously performed a task that taxed executive function, suggesting that this processing was cognitively efficient.

These findings show that adults' performance on Level-1 perspective problems has quite different cognitive characteristics depending on whether it is assessed via direct or indirect measures. However, on its own this does not secure the conclusion that adults have two systems for perspective-taking, for it remains possible that direct and indirect measures simply vary in the incidental processing demands that they place while they access the same underlying perspective-taking ability. It is also the case that evidence of an automatic and cognitively efficient capacity for perspective-taking in adults does not guarantee that the same capacity will be present in children. We address these points in turn.

One possibility is that direct and indirect measures of perspective-taking are tapping into distinct cognitive systems that make complementary trade-offs between flexibility and efficiency (Apperly & Butterfill, 2009). Importantly, on this account, the flexible system should be capable, in principle, of any form of perspective-taking (though of course, more complex problems may in practice exceed a participant's general processing capacity). In contrast, the efficient system gains efficiency at the expense of flexibility, and so should be systematically limited to process only certain kinds of problem. Apperly and Butterfill (2009) conjecture that the Level-1/Level-2

distinction may mark one such limit on efficient processing. This leads to the prediction of an asymmetry between the results obtained from direct and indirect measures on Samson et al.'s paradigm if it were posed as a Level-2 rather than a Level-1 problem: Adults should of course be capable of making Level-2 judgements when directly asked to do so, and these judgements should be subject to egocentric interference in the same way as their explicit Level-1 judgements; in contrast adults should not show evidence of Level-2 perspective-taking when assessed on indirect measures, because the automatic and cognitively efficient process tapped by these measures does not support Level-2 perspectives. This prediction was tested in the current experiment.

What of the developmental origins of automatic processing of perspectives? Surtees and Apperly (in press, Chapter 2) replicated the findings of Samson et al. (2010) and extended them by using the same paradigm with children from the age of 6-11. The effect of automatic perspective-taking was observed in children of all age groups, and to a statistically similar degree. Surtees and Apperly (in press, Chapter 2) suggested that there were two plausible alternatives as to the origins of this process. First, perspective-taking of this kind may be *originally automatic*. That is, even in infancy, processing of Level-1 perspectives may in certain situations be an efficient and automatic process, and so the mechanism identified through an indirect measure by Samson et al (2010) is the same mechanism identified with indirect measures in studies of infants (Luo & Baillargeon, 2007; Sodian et al., 2007). If this were the case, it would help explain how infants succeed on such perspective-taking tasks despite lacking the memory and executive processes that are typically necessary for “theory of mind” reasoning. Alternatively, perspective-taking may not be *originally*

automatic, but instead might be *automatised*. That is to say, perspective-taking may always be effortful when infants or children first begin to show these abilities, but it may become automatic with repeated, long-term, practice.

The most direct way of testing between these two hypotheses of original automaticity and automatisisation would be to test for the automaticity of perspective-taking in even younger children. Pilot work suggested that this is not possible using the current paradigm. An alternative is to investigate the plausibility that *automatisation* of Level-1 perspective-taking has already occurred by the age of 6 in children. This can be tested indirectly, for if children gain enough experience with Level-1 perspective-taking for it to be automatised by the age of six, there is reason to expect that children will have gained enough experience with Level-2 perspective-taking for it to be automatised, at the very latest, by the time they are older children or adults. Accordingly, if we have grounds for thinking that Level-2 perspective-taking is not automatic in adults (suggesting that it is neither originally automatic, nor automatised), then it is less likely that automatic processing of Level-1 perspectives is the result of automatisisation.

To recap, we wanted to investigate the cognitive characteristics of Level-2 perspective-taking in children and adults in order to answer two questions. First, do direct versus indirect measures of perspective-taking tap into different cognitive processes or are the distinct findings from these measures just a reflection of different task demands? Second, is automatic perspective-taking originally automatic or a consequence of automatisisation?

We tested children and adults on a Level-2 perspective-taking task adapting the paradigm initially used by Samson et al (2010). Participants made judgements about either their own perspective or that of a cartoon avatar. In Flavell's classic Level-2 perspective-taking experiment (Flavel et al., 1981) children had to report whether a turtle was "the right way up" or "upside down". Instead of using abstract terms such as these, we used numerals; specifically the numbers 6 and 9 which appear as each other when viewed upside down and the numbers 0 and 8 each of whose appearance is unaltered when viewed upside down.

This task yields both a direct and an indirect measure of perspective-taking. On the direct measure, when participants explicitly judged what the cartoon avatar saw, we expected younger children to be slower and more error prone than older children or adults, and we expected to observe egocentric interference (worse performance when the avatar's perspective was different from the participants') at all ages. On the indirect measure, when participants explicitly judged their own perspective, we expected younger children to be slower and more error prone overall, but unlike previous findings with a Level-1 version of the task (Qureshi et al., 2010; Samson et al., 2010; Surtees & Apperly, in press, Chapter 2), we did not expect automatic Level-2 perspective-taking, and so we did not expect to see any difference in performance on trials on which the avatar's perspective was different from the participant's.

3.2 Experiment 2

3.2.1 *Method*

On every trial participants viewed a cartoon picture of an avatar standing on the other side of a table (See Figure 3.1). A single numeral (0, 6, 8 or 9) was placed either on the wall, or on the table. On “Self” trials, participants judged the numeral as it appeared to themselves. On “Other” trials, participants judged how the numeral appeared to the avatar in the scene. On Stimulus-Ambiguous trials, the numeral used was a 6 or a 9 (numerals that look different if inverted.) On Stimulus-Unambiguous trials, the numeral used was a 0 or an 8 (numerals that looked the same if inverted). On Location-Wall trials the numeral was placed on the wall (so that it always appeared the same to the participant and the cartoon avatar). On Location-Table trials the numeral was placed on the table so that the avatar’s position in the room meant that he saw Ambiguous stimuli as a different number (but Unambiguous stimuli as the same). Involuntary taking of an irrelevant perspective would be evidenced by an interaction between Stimulus and Location: any effect of Location should be greater when the stimulus is Ambiguous (as this is the only time perspectives diverge).

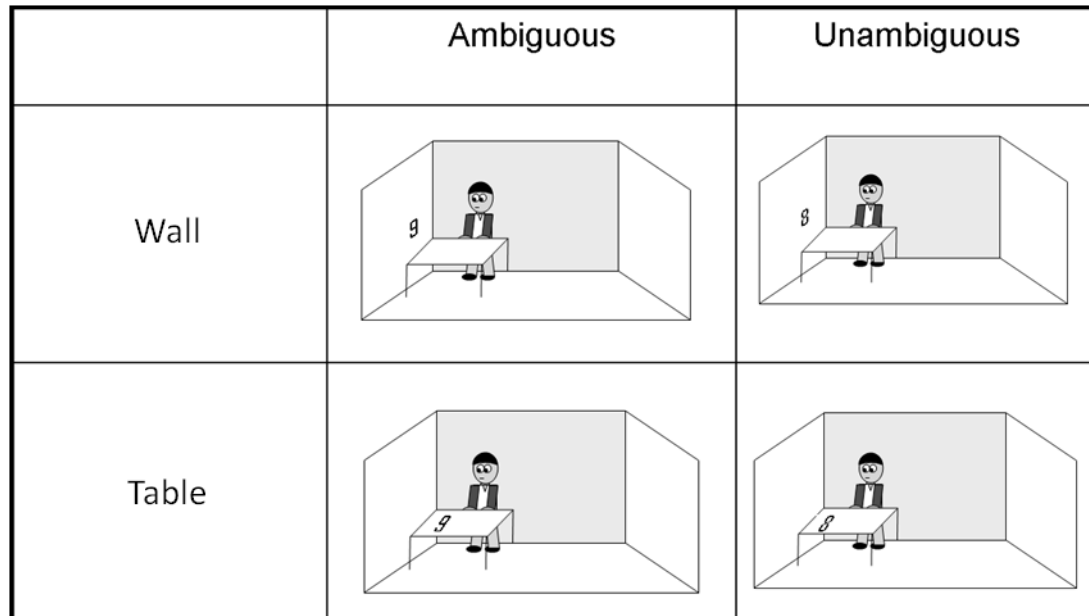


Figure 3.1. Examples of stimuli used. Ambiguous stimuli appear different if inverted, Unambiguous stimuli appear the same. Wall stimuli appear the same to Self and Other, Table Stimuli are viewed inverted. Only on Ambiguous-Table trials are Self and Other perspective content different.

3.2.1.1 Participants

Adult participants were Undergraduates and Postgraduates from the University of Birmingham (N = 20, mean age = 20.4, 18 female). Child participants attended a school in a lower-middle class area of Wolverhampton. Children between the ages of 6 and 11 were tested (mean age = 9.67, N = 80, 41 female). A median split based on Age was performed to create a group of younger children (Age range: 6.6-9.2 Years, Mean Age = 8.38 years, 24 female) and a group of older children (Age range = 9.2-11.6, Mean Age = 10.95, 17 female).

3.2.1.2 Design and Procedure

Child participants completed the experiment in a room adjacent to their normal classroom. Adult participants used a testing cubicle. Instructions included a detailed description of the procedure and an instruction to respond as quickly and accurately as possible. Practice trials were completed on paper until the participant had successfully answered examples from each condition.

On each trial, participants viewed successive fixation stimuli (a smiling face (600ms) and a fixation cross (600ms)) followed by a 1800ms auditory stimulus (either “He sees a Y” or “You see a Y”, where Y was either 0, 6, 8 or 9) and then the test picture. Participants pressed one of two coloured keys to indicate whether or not the auditory stimulus correctly described the picture. Response time was measured from the onset of the picture. Child participants completed 4 practice trials, followed by 60 test trials (split evenly between Self and Other and presented in pseudo-random order). Adults completed 120 trials organised to the same criteria. The experiment was presented using E-prime 2.0 (Psychology Software Tools, Inc.) on a laptop computer.

3.2.2 Results

Self and Other judgements measured very different perspective-taking effects. Other perspective-taking provided a “Direct” measure of voluntary perspective-taking. Self perspective-taking provided an “Indirect” measure of any involuntary perspective-taking which may have taken place. Data from these Direct and Indirect measures were analysed separately as we had no hypotheses relating to their comparison. Main effects of Stimulus examined whether there was any extra difficulty in processing Ambiguous stimuli (Containing 6s or 9s) rather than Unambiguous stimuli

(Containing 8s or 0s). Main effects of Location examined whether presentation of the digit on the wall or table affected performance, whether or not this location resulted in a perspective difference between self and other. The critical effect for our hypotheses concerned the interaction between Stimulus and Location. This investigated interference between contents of Self and Other perspectives, because only in Ambiguous-Table trials does the perspective content of the character differ from that of the participant. For Other perspective trials (i.e., our direct measure) an interaction between Ambiguity and Location would be the result of egocentric interference from self on to other. For Self trials (i.e., our indirect measure), an equivalent Ambiguity by Location interaction would provide evidence for interference from the perspective of other when making judgements about the self.

3.2.2.1 Direct measure of Perspective-taking

Children's and adults' data were analysed separately as adults completed a greater number of trials.

3.2.2.1.1 Children

Response Times (RTs). Data that were two and a half standard deviations from the mean were omitted from the analysis of RTs (accounting for between 1% and 3% of data for each age group) as were data from incorrect responses.

An ANOVA with Stimulus and Location as within subjects factors, and Age as a between subjects factor revealed a main effect of Age ($F(1, 79) = 31.46, p < .001, \eta^2 = .29$, Older < Younger). There was a main effect of Location ($F(1, 79) = 86.77; p < .001, \eta^2 = .53$; Wall < Table) and a main effect of Stimulus ($F(1, 79) = 82.73, p <$

.001, $\eta p^2 = .52$; Unambiguous < Ambiguous). There was a significant interaction between Location and Stimulus ($F(1, 79) = 15.30$, $p < .001$, $\eta p^2 = .17$). The effect of Location was significant for Unambiguous ($t(79) = 4.31$, $p < .001$) trials, but was greater for Ambiguous trials ($t(79) = 8.92$, $p < .001$.) There were no other significant interactions. ($F(1, 77) \leq 1.50$, $p \geq .23$, $\eta p^2 \leq .019$)

Errors. A similar ANOVA on errors revealed a main effect of Location ($F(1, 79) = 7.62$, $p = .007$, $\eta p^2 = .089$; Wall < Table). There was no main effect of Age ($F(1, 79) = .096$, $p = .76$, $\eta p^2 = .001$) and no main effect of Stimulus ($F(1, 79) < .001$, $p = .99$, $\eta p^2 < .001$). There were no significant interactions ($F_s \leq 1.70$, $p_s \geq .20$).

3.2.2.1.2 Adults

Response Times. An ANOVA with Stimulus and Location as within subjects factors revealed a main effect of Location ($F(1, 19) = 83.76$; $p < .001$, $\eta p^2 = .82$; Wall < Table) and a main effect of Stimulus ($F(1, 19) = 33.50$, $p < .001$, $\eta p^2 = .64$; Unambiguous < Ambiguous). There was a significant interaction between Location and Stimulus ($F(1, 19) = 8.50$, $p = .009$, $\eta p^2 = .009$). The effect of Location was significant for Unambiguous ($t(19) = 2.74$, $p = .013$) trials, but was greater for Ambiguous trials ($t(19) = 6.62$, $p < .001$).

Errors. An ANOVA with Stimulus and Location as within subjects factors revealed no main effect of Location ($F(1, 19) = .79$; $p = .39$, $\eta p^2 = .005$), no main effect of Stimulus ($F(1, 19) = .79$, $p = .39$, $\eta p^2 = .04$; Unambiguous < Ambiguous) and no significant interaction between Location and Stimulus ($F(1, 19) = .099$, $p = .76$, $\eta p^2 = .005$).

3.2.2.2 Self Trials

3.2.2.2.1 Children

Response times. An ANOVA with Stimulus and Location as within subjects factors, and Age as a between subjects factor revealed a main effect of Age ($F(1, 79) = 30.09, p < .001, \eta p^2 = .28$, Older < Younger). There was a main effect of Location ($F(1, 79) = 59.03; p < .001, \eta p^2 = .43$; Wall < Table) and a main effect of Stimulus ($F(1, 79) = 29.90, p < .001, \eta p^2 = .28$; Unambiguous < Ambiguous). There was a significant interaction between Age and Stimulus ($F(1, 79) = 4.08; p = .047, \eta p^2 = .050$). Older children ($t(40) = 4.45, p < .001$) showed a stronger effect of stimulus than younger children ($t(40) = 4.10, p < .001$), but the effect was significant for both. The critical interaction between Location and Stimulus was not significant ($F(1, 79) = .94, p = .33, \eta p^2 = .01$), nor were any other interactions ($(F(1, 79) \leq 1.35, p \geq .25, \eta p^2 \leq .017)$).

Accuracy. A similar ANOVA on errors revealed main effects of Location ($F(1, 79) = .029, p = .049, \eta p^2 = .049$) and Stimulus ($F(1, 79) = 12.34, p = .001, \eta p^2 = .14$; Wall < Table), but no main effect of Age ($F(1, 79) = .018, p = .89, \eta p^2 < .001$). There were no significant interactions ($F_s \leq 2.67, p \geq .11, \eta p^2 \leq .033$), with the critical interaction between Stimulus and Location not significant ($F(1, 79) = 1.39, p = .24, \eta p^2 = .018$).

3.2.2.2.2 Adults

Response Times. An ANOVA with Stimulus and Location as within subjects factors revealed a main effect of Location ($F(1, 19) = 10.42; p < .001, \eta p^2 = .35$; Wall

< Table) and a main effect of Stimulus ($F(1, 19) = 20.19, p < .001, \eta^2 = .52$; Unambiguous < Ambiguous). There was a significant interaction between Location and Stimulus ($F(1, 19) = 7.76, p = .012, \eta^2 = .29$). The effect of Location was significant for Ambiguous trials ($t(19) = 5.41, p < .001$), but not for unambiguous trials ($t(19) = .89, p = .38$).

Accuracy. An ANOVA with Stimulus and Location as within subjects factors revealed a main effect of Stimulus ($F(1, 19) = 8.28, p = .010, \eta^2 = .30$; Unambiguous < Ambiguous), but no main effect of Location ($F(1, 19) = 2.84; p = .11, \eta^2 = .13$). There was also no significant interaction between Location and Stimulus ($F(1, 19) = 1.07, p = .32, \eta^2 = .053$).

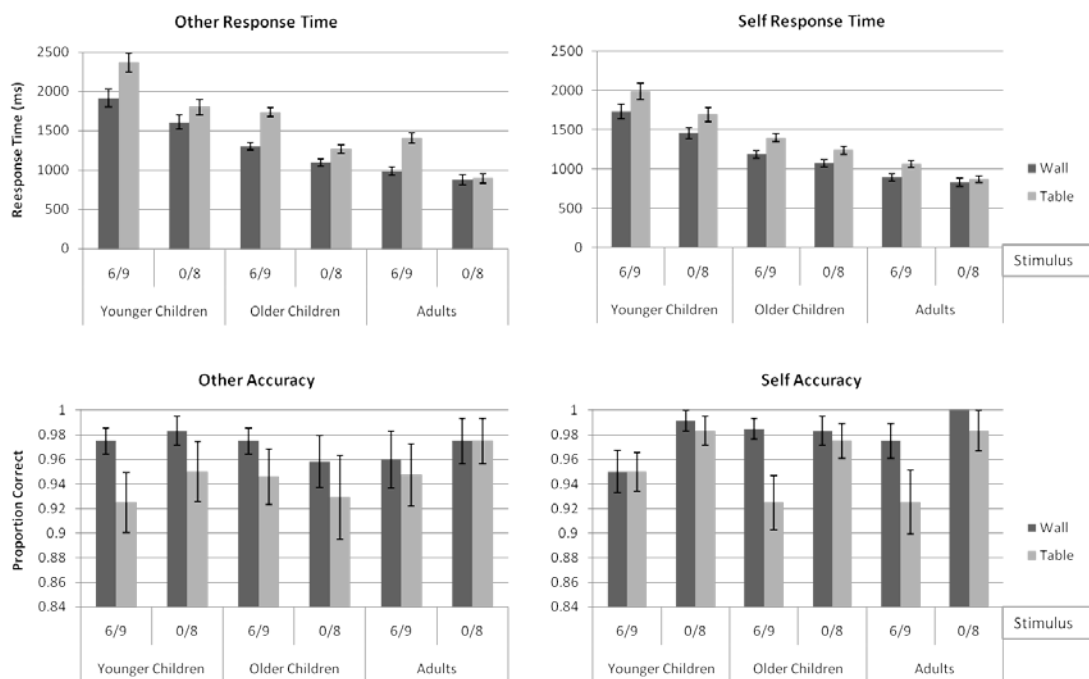


Figure 3.2. Response Times and Accuracy of all age groups in Experiment 2.

3.2.2.3 Summary

Results from adults differed critically from those of children for self perspective-taking response times. An interaction between Stimulus and Location when judging their own perspective suggested adults were automatically taking the avatar's perspective. We considered two possible explanations for this. Firstly, given their longer experience, adults may have automatised perspective-taking, whereas the children in our study have not yet had sufficient time or experience for automatisation. Secondly, adults may have automatised some element of the current task within the experimental session; recall they completed twice as many trials as children. To resolve this we re-analysed the adult data, but with the experiment split into two halves: if some form of automatisation had occurred during the session, interference should increase with time.

3.2.2.4 First Half of Experiment

Initially we analysed the first half of the experiment so as to match the number of trials the child participants had received.

3.2.2.4.1 Other perspective-taking

Response times. An ANOVA with Stimulus and Location as within subjects factors revealed a main effect of Location ($F(1, 19) = 34.79; p < .001, \eta p^2 = .65$; Wall < Table) and a main effect of Stimulus ($F(1, 19) = 11.713, p < .001, \eta p^2 = .38$; Unambiguous < Ambiguous). There was a significant interaction between Location and Stimulus ($F(1, 19) = 6.57, p = .019, \eta p^2 = .26$). The effect of Location was significant for Ambiguous trials ($t(19) = 5.23, p < .001$), but not for Unambiguous trials ($t(19) = 1.71, p = .10$).

Errors. A similar ANOVA on errors revealed a main effect of Stimulus ($F(1, 19) = 7.29$; $p = .014$, $\eta p^2 = .28$; Unambiguous < Ambiguous), but no main effect of Location ($F(1, 19) = .42$, $p = .53$, $\eta p^2 = .022$), and no significant interaction ($F(1, 19) = .42$, $p = .53$, $\eta p^2 = .022$).

3.2.2.4.2 Self Perspective-taking

Response times. An ANOVA with Stimulus and Location as within subjects factors revealed a main effect of Location ($F(1, 19) = 8.31$; $p = .010$, $\eta p^2 = .30$; Wall < Table) and a main effect of Stimulus ($F(1, 19) = 6.27$, $p = .022$, $\eta p^2 = .25$; Unambiguous < Ambiguous). There was no significant interaction between Location and Stimulus ($F(1, 19) = .45$, $p = .51$, $\eta p^2 = .023$).

Errors. A similar ANOVA on errors revealed a trend towards a main effect of Stimulus ($F(1, 19) = 3.18$; $p = .091$, $\eta p^2 = .14$; Unambiguous < Ambiguous), but no main effect of Location ($F(1, 19) = .15$, $p = .71$, $\eta p^2 = .008$), and importantly no significant interaction ($F(1, 19) = .15$, $p = .71$, $\eta p^2 = .008$).

3.2.2.5 Second Half of Experiment

3.2.2.5.1 Other perspective-taking

Response times. An ANOVA with Stimulus and Location as within subjects factors revealed a main effect of Location ($F(1, 19) = 35.63$; $p < .001$, $\eta p^2 = .66$; Wall < Table) and a main effect of Stimulus ($F(1, 19) = 12.61$, $p = .002$, $\eta p^2 = .66$; Unambiguous < Ambiguous). There was a significant interaction between Location and Stimulus ($F(1, 19) = 7.57$, $p = .013$, $\eta p^2 = .30$). The effect of Location was

significant for Ambiguous trials ($t(19) = 6.22, p < .001$), but not for Unambiguous trials ($t(19) = 1.11, p = .28$).

Errors. A similar ANOVA on errors revealed no main effect of Stimulus ($F(1, 19) = 1.00; p = .33, \eta p^2 = .050$), no main effect of Location ($F(1, 19) = .015, p = .91, \eta p^2 = .001$), and no significant interaction ($F(1, 19) = .13, p = .72, \eta p^2 = .007$).

3.2.2.5.2 *Self Perspective-taking*

Response times. An ANOVA with Stimulus and Location as within subjects factors revealed a main effect of Location ($F(1, 19) = 6.21; p = .022, \eta p^2 = .25$; Wall < Table) and a main effect of Stimulus ($F(1, 19) = 12.33, p = .002, \eta p^2 = .39$; Unambiguous < Ambiguous). There was a significant interaction between Location and Stimulus ($F(1, 19) = 5.88, p = .025, \eta p^2 = .24$). The effect of Location was significant for Ambiguous trials ($t(19) = 3.68, p = .002$), but not for Unambiguous trials ($t(19) = .015, p = .99$).

Errors. A similar ANOVA on errors revealed a main effect of Stimulus ($F(1, 19) = 4.40; p = .050, \eta p^2 = .19$; Unambiguous < Ambiguous) and a main effect of Location ($F(1, 19) = 4.40, p = .050, \eta p^2 = .19$, Wall < Table), but no significant interaction ($F(1, 19) = 1.41, p = .25, \eta p^2 = .069$).

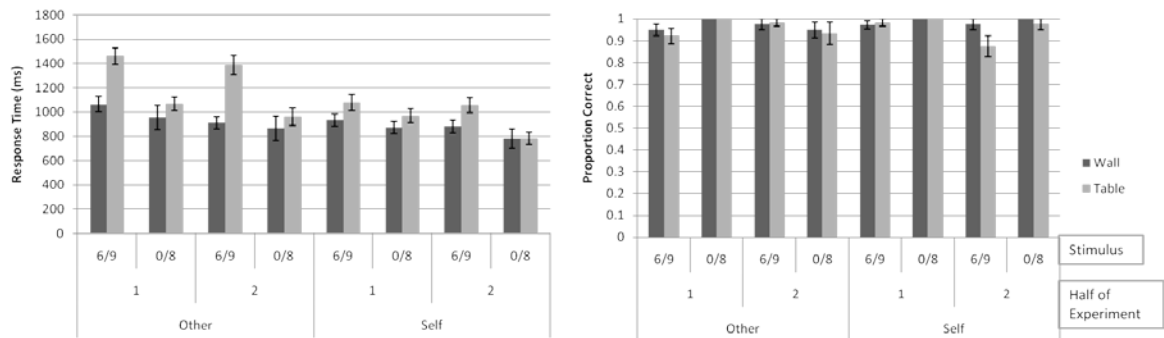


Figure 3.3. Response Times and Accuracy of adults in Experiment 2, organised by half of experiment.

Adults only showed interference from the perspective of other in the second half of the experiment, whereas interference from self perspective was always evident. This suggests that repeated experience with the task did not enable adults to overcome their tendency for egocentric interference when making direct perspective judgements, but repeated experience did result in some kind of automatisisation as evidenced on the indirect measure. We discuss the likely nature of this automatisisation below.

3.3 Discussion

Participants found taking another's perspective more difficult when the target character viewed a numeral upside down (in Table trials), and also when the numeral viewed could look different if seen from a different angle (in Ambiguous trials). Importantly for our hypotheses, there was also an interaction between these factors. On "Other" trials, directly judging another's perspective was particularly difficult in trials when one's own perspective *content* and that of another actually differed, suggesting interference from one's own perspective when judging that of another. On Self trials (our indirect measure of perspective-taking), we again observed that judgements were more difficult if another viewed a stimulus upside down and also

when the numeral viewed could look different if seen from another angle. In children we did not, however, observe an interaction between these factors. Those trials where the target's perspective content was different from the participant's own were processed with no extra difficulty, over and above the independent contribution of the location and the type of the stimulus. There is no evidence, then, that child participants were calculating the perspective of another except when the instructions for the trial meant that this was necessary. Adults, on the other hand did show evidence of an interaction between location and stimulus type, however this was only evidenced in the second half of the experiment, suggesting that within the experiment itself they had automatised a process that originally required cognitive effort.

3.3.1 Egocentrism in direct perspective judgements

Egocentrism – the interference from one's own perspective when taking that of another – is a feature of perspective-taking in young children (Flavell et al., 1981a; Light & Nix, 1983; Piaget & Inhelder, 1956): when young children make errors on perspective-taking tasks, they most commonly make errors in line with their own perspective, not at random. More recently, evidence from adults has suggested that it is not only children who suffer egocentric effects (Bernstein, Atance, Loftus, & Meltzoff, 2004; Birch & Bloom, 2007; Epley et al., 2004a; Keysar, Lin and Barr, 2003; Nickerson, 1999; Royzman, Cassidy & Baron, 2003). Adults rarely make egocentric errors in optimal conditions, but when they have to make estimates (Bernstein et al., 2004) or perform tasks quickly (Samson et al., 2010; Keysar et al., 2003), they do show egocentric biases. One interpretation of this is that children's egocentric errors and adults' egocentric biases are largely unrelated: tasks with adults often involve much more complex information and reasoning, and there is often no

certainty as to whether a normatively correct response is indeed appropriate. Alternatively these effects may in fact be symptoms of the very same problem: it may be more difficult to process perspectives of others if they differ from one's own and this processing cost may lead to errors in young children, but merely biases in older children and adults who have more cognitive resources available.

One way to distinguish between these two interpretations is to test older children and adults on the very same tasks that young children fail. Our results suggest that egocentric errors in young children's Level-2 perspective-taking are the result of the very same processing problem that affects older children and adults. In our Level-2 perspective-taking task, children from the age of 6 showed egocentric interference effects very similar to those of adults. It is always difficult to ignore how one sees an object, and this may cause young children to make mistakes, and adults to perform more slowly, or less accurately under time pressure.

What our results do not address is whether this egocentrism is the result of anchoring and effortful adjustment (Epley et al., 2004a, 2004b) or of it being difficult to inhibit a strong self representation when creating an entirely separate perspective for another. An anchoring and adjustment interpretation would suggest that when we explicitly take others' perspectives, egocentrism is the result of participants first having to calculate their own perspective and then, for trials involving incompatible perspectives, having to adjust away from this. Alternatively, putting one's own perspective aside when calculating the perspective of another may be what causes difficulties. Future investigation could address this question through independently manipulating the need for adjustment and the salience of one's own perspective.

3.3.2 Automatisisation versus original automaticity: evidence from the indirect measure of perspective-taking

Using an indirect measure, Samson et al. (2010) found adults to automatically take the Level-1 perspectives of other people, and Apperly and Butterfill (2010) conjectured that such effects might be limited to Level-1 perspective-taking. Surtees and Apperly (in press, Chapter 2) replicated evidence of automatic Level-1 perspective-taking in adults, and showed a statistically equivalent degree of interference from another's perspective in children as young as six. This prior work, although suggestive of originally automaticity, left open the possibility that Level-1 perspective-taking is automatised over extended developmental time. This is potentially important because only originally automatic perspective-taking could help to explain infants' success on some theory of mind tasks in spite of absent or reduced language and executive function. Automatisation could not, as this would require earlier effortful processing.

We reasoned that if the true origin of automatic Level-1 perspective-taking was automatisation then, given sufficient experience, children should also automatise Level-2 perspective-taking. Even allowing for the possibility that humans engage in Level-2 perspective-taking somewhat less frequently than Level-1 perspective-taking, we supposed that if automatisation is possible then it should have occurred by adulthood. In fact, children in our study showed no evidence that they were automatically processing the Level-2 perspectives of another, and nor did adults over the same number of experimental trials. Nonetheless, it was the case that in the second half of the experiment, adult participants were slower at judging their own perspective when the avatar's perspective was different, suggesting that some form of automatisation had occurred. The critical question is, what had been automatised?

One possibility is that adult participants actually automatised Level-2 perspective-taking, suggesting that the problem of processing Level-2 perspectives is automatisable, at least in principle. We do not favour this interpretation since we think that if adults could achieve such automatisation in a few minutes of a laboratory experiment, then their entire lifetime of prior experience with perspective-taking ought to have led them to have already automatised a long time before they became participants in our study. A second possibility is that adults automatised something very specific about the task. For example, during the task numerals “6” and “9” were both repeatedly interpreted as both 6 and 9 depending on their location of presentation and the perspective that participants were asked to judge. It seems plausible that this repeated experience led participants presented with “6” in the stimulus to activate responses for both 6 and 9. The important point is that this would yield the interference effect that we observed on the indirect perspective-taking measure, not because participants had automatised Level-2 perspective-taking, but because participants had formed highly task-specific stimulus-response associations. Such associations would, of course, not generalise to any other Level-2 perspective-taking task.

In sum, we think that the most important finding is that naive adults, who have only limited experience on the task, show no evidence of automatic processing of the avatar’s Level-2 perspective, and nor do either group of children in this study. We suggest that the fact that even adults have not automatised Level-2 perspective-taking makes it unlikely that children have automatised Level-1 perspective-taking by the age of 6.

3.3.3 *Limits on efficient, automatic perspective-taking*

Exciting and controversial recent research suggests that human infants and some non-human species may be capable of perspective-taking and that these abilities are most likely to be observed on indirect measures, such as looking time or spontaneous behaviour (e.g., Call & Tomasello, 2008; Emery & Clayton, 2004; Onishi & Baillargeon, 2006; Santos, Nissen & Ferrugia, 2006; Sodian et al., 2007; Song & Baillargeon, 2008; Southgate, Senju & Csibra, 2006; but note that there is also some evidence of perspective taking on more direct measures, e.g. Buttelman, Carpenter & Tomasello, 2009). It is striking that when children are directly asked about what another person sees, knows or believes, they generally perform significantly less well (e.g., Flavell et al., 1981; Wellman, Cross & Watson, 2001), and indeed, it is possible for the very same individual to be simultaneously “incorrect” and “correct”, depending on whether their ability is measured directly or indirectly (e.g., Clements & Perner, 1994). Samson et al. (2010) likewise used both direct and indirect measures to assess Level-1 perspective-taking in older children and adults (see further Qureshi, Apperly & Samson, 2010; Surtees & Apperly, in press, Chapter 2). Findings from the direct measure fit with a large literature suggesting that explicit perspective judgements are relatively effortful and prone to egocentric interference. Findings from the indirect measure suggested that Level-1 perspectives can be processed relatively automatically and with little cognitive effort. However, one problem with interpreting these findings – and the reason why the findings from infants and non-human animals have proved so controversial – is that it is just not clear whether direct and indirect measures are simply alternative ways of assessing the same underlying ability or whether they are in fact tapping quite different cognitive processes.

Apperly and Butterfill (2009) propose that one way of explaining the pattern of results is to suppose that humans have multiple systems for theory of mind, some of which trade flexibility to gain efficiency and others which do the reverse. The efficient systems might be common to adults, infants, and perhaps also some non-human animals, and might not necessarily be available for explicit report on direct measures. Importantly, this provides a theoretically motivated prediction that can assist with interpreting the findings from direct and indirect tests: if it is the case that indirect measures are tapping a cognitive process that has gained efficiency at the expense of flexibility, then there really must be limits to the problems that it can handle. Apperly & Butterfill (2009) offered the Level-1/Level-2 distinction as a candidate for one such signature limit.

The current findings support this prediction, by showing that older children and adults, who can, clearly, succeed on direct tests of Level-2 perspective-taking, show no evidence of Level-2 perspective-taking on our indirect measure. Absence of evidence does not, of course, constitute evidence of absence, but we should be interested when absence of evidence repeatedly converges on the same conclusion across multiple studies and multiple participant groups. This is the case in the literature on number cognition, where there is evidence that human adults, human infants and non-human animals are all capable of precise enumeration, and convergence on the conclusion that this ability is limited to sets of no more than 3 or 4 items (e.g., Feigenson, Dehane & Spelke, 2004). It is noteworthy, therefore, that in addition to the absence of evidence from adults reported here, there is no evidence that either infants or non-human animals are capable of Level-2 perspective-taking. We suggest that this convergence should make us take seriously the proposition that

indirect measures are tapping a cognitively efficient capacity for perspective-taking that is limited to process Level-1 perspective problems.

3.3.4 Problems with the distinction between Level-1 and Level-2 perspective-taking

We have appealed to the distinction between Level-1 and Level-2 perspective-taking in formulating a hypothesis about signature limits of efficient perspective-taking. This distinction, although useful, suffers from several defects when considered as a signature limit. In one canonical formulation, Level-1 perspective-taking involves being able to infer “what another person does and does not see” whereas Level-2 perspective-taking involves knowing that “an object simultaneously visible to both the self and the other person may nonetheless give rise to different visual impressions or experiences” (Flavell, Everett, Croft & Flavell, 1981, p. 1). A first defect with this formulation for our purposes (although not for Flavell and colleagues’) is that it is specific to vision. For our purposes a more general distinction would be better, one that not only applies to multiple perceptual modalities but can also be applied to cognitive as well as experiential states. And there is no theoretical reason to stipulate that Level-2 perspective-taking concerns objects visible to all (this may be an operational requirement). Second, Level-2 perspective-taking requires understanding that objects give rise to experiences. However, standard tests for Level-2 perspective-taking, including Flavell et al.’s (1981), do not test this requirement. To see why not, consider Flavell et al.’s stimulus: a rabbit that appears yellow when viewed from one angle and green when viewed from another. These appearances are not properties of any particular subject; in general they can be enjoyed by any observer with normal colour vision who is appropriately located and oriented. In principle, then, participants could succeed on this Level-2 task by representing appearance properties

of objects rather than experiential properties of subjects (Nudds, 2010). The same applies to recent studies of adults that equate Level-2 perspective-taking with the ability to rotate oneself into the physical position of another (e.g., Kessler & Thomson, 2010; Michelon & Zacks, 2005). Understanding that objects give rise to experiences is not in principle necessary for success on these tasks: understanding that objects have appearance properties accessible from different points of view would be sufficient. A more direct test of Level-2 perspective-taking as defined above would involve properties like blurriness which are not tracked by any of an object's subject-independent appearances (Smith, 2007). In short, then, the above canonical definition of Level-2 perspective-taking concerns an experiential, subject-dependent notion of perspective whereas actual tests may well measure abilities to compute a non-experiential, subject-independent notion of perspective. Lack of fit between the canonical definitions and standard tests can lead to conflating these two notions of perspective (and in some places Level-2 perspective taking is defined in terms of appearance properties of objects (Masangkay et al., 1974, p. 360; Flavell, 2000, p. 19), potentially adding to the confusion). The difference between these two notions of perspective may be relevant to identifying signature limits of efficient perspective-taking.

It is possible to overcome these deficiencies while retaining the substance of the conclusions we have drawn. A perspective is a collection of objects, properties, states, facts and events associated with a particular individual. There are two dimensions along which perspectives can be distinguished: we can distinguish them according to the sorts of thing they contain, and we can distinguish them according to the nature of the association that has to obtain between a perspective and an individual

in order for the perspective to be her perspective. We consider each dimension in turn. First, perspectives can be sparse or rich. A sparse perspective might include only objects and their locations in a frame of reference centred on the associated individual. A richer perspective might include properties such as the shapes and colours of objects; and a still richer perspective might include facts about how the objects appear from the location or state occupied by the associated individual. In the Level-1 perspective-taking tasks discussed here, only sparse perspectives are needed. One possibility consistent with our findings is that the signature limits of efficient perspective-taking involve degrees of sparseness: only where perspective-taking involves relatively sparse perspectives can it be efficient. (This leaves open the question of just how sparse the perspectives involved in efficient perspective-taking need to be.)

So far we have been considering distinguishing perspectives with respect to how sparse their contents are. We can also distinguish perspectives along a second dimension: the nature of the association that must hold between the perspective and an individual if the perspective is to be the perspective of that individual. For instance, we can distinguish *subject-independent perspectives* which exist independently of any particular individual and can become the perspective of an individual just in virtue of their being suitably equipped, located in the right place at the right time, and appropriately oriented. In everyday life people sometimes talk about going somewhere to see the view, where the view is something that can be enjoyed by multiple individuals on different occasions; such views are examples of subject-independent perspectives. In all the experiments we have discussed, both Level-1 and Level-2, subjects could in principle have succeeded by representing

subject-independent perspectives only. (Whether this is possible in practice is as yet unknown: participants may have solved our Level-2 tasks by representing visual experiences.) Other kinds of perspective cannot be the perspective of an individual without her having a particular history, emotion, perceptual experience, registration, belief or intention. This kind of perspective is invoked when someone who falsely believes that the chocolate is in the cupboard is said to have an incorrect, or out of date, perspective on the world (not the sort of thing one can enjoy by visiting a viewpoint). Signature limits on efficient perspective-taking may concern both dimensions: efficient perspective-taking may be efficient only because there are limits on the richness of the contents of perspectives that can be computed and also only because there are limits on the complexity of the association between individuals and perspectives that can be computed.

The distinction between Level-1 and Level-2 perspective-taking is a useful shorthand for the conjecture that efficient perspective-taking is limited with respect to one or both of these dimensions in some way that is yet to be specified more precisely. The distinction between Level-1 and Level-2 as we have been using it is not supposed to imply more than this. In particular, we are not committed to the claim that perspective-taking involving perceptual experiences cannot be efficient.

The conclusion we are led to, by our data and the foregoing considerations, is that there are two routes to calculating some kinds of sparse or subject-independent perspectives ('Level-1' perspectives): one automatic, but inflexible and the other flexible, yet consuming of cognitive resources. Perspective-taking involving richer perspectives or those which are not subject-dependent ('Level-2' perspectives), on the

other hand, generally, seems to require effortful processing, which comes with the bonus of flexibility: this probably explains why infants are yet to demonstrate this ability. The fact that Level-1 perspective-taking seems to be originally automatic also supports the notion that two systems may be involved in perspective-taking: it is not the case that extra practice improves speed at the cost of flexibility: fast, efficient processing seems to be developmentally primary, with flexible processing coming with the acquisition of cognitive resources.

Future work should focus on attempting to find whether the Level-1/Level-2 distinction really does roughly approximate a signature limit on the abilities of infants', non-human animals' and adults' involuntary processing. This may be relevant not only to understanding processes underpinning, and limits on, visual perspective-taking but also to understanding processes underpinning, and limits on, theory of mind abilities more generally. As outlined above, it is possible to generalise a Level-1/Level-2 distinction so that it applies not only to visual perspective-taking but also to the representation of mental states such as knowledge and belief. The fact that Level-1 perspective-taking may be underpinned by automatic processes indicates the possibility that other Level-1-type problems can be solved by processes that are cognitively efficient. The importance of this is that it may provide some explanation for limited but foundational theory of mind abilities in infants (and perhaps other animals), who have limited cognitive capacities for language and executive control.

3.4 Summary and Links to Chapter 4

In Chapter 3 we suggested that the Level-1/Level-2 distinction may be a limit on efficient ToM, or at least on efficient visual perspective-taking. It was made clear that the Level-1/Level-2 distinction lacked in several respects for it to be considered a signature limit, but that currently this approximation provided a strong starting point.

Whilst it was clear in Chapter-2 that the perspective of the avatar was being computed efficiently, in Chapter-3 this was not the case. It was suggested that the type of information represented as a perspective in Chapter-2, for example two objects, was calculated by a route to perspective-taking that was not available for the type of information represented as a perspective in Chapter-3, for example the number 9. There were, however, differences other than the content of the perspective between the paradigms presented in Chapters 2 and 3. In particular, in Chapter 2 the avatar's viewpoint was perpendicular to that of the participant (See Figure 2.1), whilst in Chapter 3 the avatar looked almost directly towards the participant (Figure 3.1). Could it be the case that participants did not automatically encode his perspective because this avatar did not cue perspective-taking as strongly? Also, the stimuli in Chapters 2 and 3 differed in the brightness of the perspective content. Could it be that automatic perspective-taking could not occur in Chapter 3 because the content was harder to determine? I find both of these suggestions unlikely, but Chapter 4 investigates these possibilities, and others like them, by testing adults' Level-1 and Level-2 perspective-taking using the very same stimuli. In this chapter, we also introduced a control task to investigate further whether there was any degree of automatic perspective-taking in our Level-2 task. Recall that in Chapter 1 we suggested comparisons to non-social tasks were vital for clear conclusions.

CHAPTER 4

Does the Level-1/Level-2 distinction provide a limit to adults' efficient perspective processing?

This chapter, largely in its current form, has been submitted as the article: Surtees, A. D. R. & Apperly I., A. (submitted), Does the Level-1/Level-2 distinction provide a limit to adults' efficient perspective processing?

4.0 Abstract

Recent evidence has suggested that there are two routes to Level-1 perspective judgements about what people can or cannot see: one which is relatively automatic and the other requiring cognitive control (Samson et al., 2010). A two-part experiment tested directly whether both these routes were available for Level-2 perspective-taking, which requires an understanding that single objects can be represented differently by different people. Experiment 3A (N=50) extended previous findings about Level-1 perspective taking, showing a role for both automaticity and control in perspective-taking when compared to a control condition in which participants made self-projections. Experiment 3B (N=50) used the very same stimuli and found no evidence of an automatic route to Level-2 perspective-taking: participants found it no more difficult to ignore an incongruent Level-2 perspective than to ignore an alternative self-projection task. We suggest then, that the only route available to Level-2 perspective-taking involves explicit judgements and is subject to egocentric interference.

4.1 Introduction

In order to predict and explain the behaviour of others in even simple social environments it is often necessary to take into account their perspective on the world. People's actions are dictated by their goals and intentions, which in turn are dictated by beliefs and desires, any of which may diverge from our own. Cooperating and competing with others regularly requires representation of these perspectives of others. One case where such situations arise is in taking visual perspectives.

The traditional method for testing perspective-taking involves asking participants (often children) to directly assess the perspectives of others and either report this perspective or make judgements about what a character will do given that they hold a given perspective. For example, Piaget and Inhelder (1956) asked children to report how an array of three mountains would appear to an experimenter and Flavell, Everett, Croft and Flavell (1981) asked children to judge whether someone sat opposite them would see a picture of a turtle as being the right way up, or upside down. Using these measures, perspective-taking seems to be effortful, and beyond the capacities of young children. Interestingly, children do not make errors at random, but errors that match their own perspective (Piaget & Inhelder, 1956; Flavell et al., 1981). Overcoming such egocentrism is thought to be crucial in the development of perspective-taking (Piaget & Inhelder, 1956).

Whilst most perspective-taking research has been carried out with young children, methods more sensitive to adults' abilities have begun to be developed (Epley, Morewedge & Keysar, 2004; Kessler & Thomson, 2010; Keysar et al., 2003; Michelen & Zachs, 2006; Samson, Apperly, Braithwaite, Andrews & Bodley-Scott, 2010), allowing for investigation of mature processing. What is perhaps surprising is that these studies have suggested that when adults have to make explicit perspective-taking judgements this requires considerable cognitive resources. All of these measures have identified egocentric interference (Epley et al., 2004, Keysar et al., 2003; Nickerson, 1999), suggesting that adults have to exercise cognitive control to ignore their own perspective. One suggestion as to why cognitive control is required for perspective-taking is that perspective-taking is achieved through egocentric anchoring and adjustment/correction (Epley et al., 2004). The process of anchoring

and adjustment is achieved through first calculating one's own perspective and then making a series of incremental adjustments until a plausible alternative for other perspective is reached. There is good evidence to suggest that some perspective-taking is achieved via incremental adjustment: a greater distance between one's own perspective and that of another seems to come at greater processing cost (Michelon & Zacks, 2005). Michelin and Zacks (2005) found evidence of a perspective-taking mechanism that requires deliberate adjustment to another's position in the form of mental rotation. Interestingly though, they also identified another mechanism for perspective-taking which did not appear to take the participant's egocentric perspective as its starting point; rather it was parametrically related to the distance between the target and an object. What is clear, though, is that whether explicit perspective-taking requires anchoring and adjustment or not, it tends to require deliberate cognitive effort in adults.

Recent research in infant (Onishi & Baillargeon, 2005; Sodian, Theormer & Metz, 2007; Southgate, Senju & Csibra, 2007; Surian, Caldi & Sperber, 2007) and comparative (Clayton & Emery, 2004; Hare, Call & Tomasello, 2001, Santos, Nissan & Feruggia, 2006) psychology has suggested that, in fact, perspective-taking might not be so difficult after all. Indirect measures, largely monitoring infants' eye gaze, but also other spontaneous behaviours, seem to show that participants with only very limited cognitive resources can track perspectives. One interpretation of such results is that researchers have finally been able to find measures sensitive enough to show how easy perspective-taking really is (Baillargeon, Scott & He, 2010; Onishi & Baillargeon, 2005). Others are more sceptical about whether such evidence counts as genuine perspective-taking or "theory of mind" (Perner & Ruffman, 2005; Ruffman &

Perner, 2005). In contrast to these rather polarised positions, it will be our working hypothesis that direct and indirect measures of perspective-taking can both reveal interesting features about the cognitive profile of perspective-taking.

Samson et al. (2010) identified both a direct and an indirect measure of perspective-taking using a single paradigm where adults judged the number of dots that could be seen on the walls of a cartoon room. On separate trials, adults took either their own perspective (Self trials) or the perspective of a cartoon avatar that was present in the room (Other trials). On Other trials participants had to ignore their own perspective to judge what the avatar saw. On this direct measure of perspective-taking participants were slower and more error-prone at judging the avatar's perspective when their own perspective was different. That is to say, adults showed egocentric interference, analogous to the errors made by very young children on analogous perspective-taking tasks, and consistent with the view that adults were making effortful, incremental adjustments to the avatar's perspective. In contrast, on Self trials, participants had no reason to process the avatar's perspective, since their only task was to judge what they themselves could see in the room. Nonetheless, participants were slower and more error prone at judging their own perspective when the irrelevant perspective of the avatar happened to be different from their own. The authors suggested that this interference might reflect the operation of a relatively automatic process for calculating the visual perspective of the avatar that operated even when it was unnecessary for the task of judging Self perspective, and indeed, when it actively impeded performance of this task. For current purposes we take this evidence of interference from the irrelevant perspective of another person when judging one's own perspective as an indirect measure of perspective-taking, and we take these

findings as consistent with the view that perspective-taking can be cognitively efficient, and even automatic, at least in some circumstances. Our key question in the current work is whether direct and indirect measures are assessing the same underlying perspective-taking ability, or whether there might be differences between the abilities tapped by these measures.

There are two reasons for supposing that there might be differences between the abilities that adults can display on direct versus indirect measures of perspective-taking. Firstly, if the abilities demonstrated on indirect measures reflect a cognitively efficient process for perspective-taking, which operates in a relatively automatic manner, then there are strong theoretical reasons for supposing that this efficiency will come at the cost of inflexibility about the kinds of perspectives that can be processed (Apperly & Butterfill, 2009). Just as human infants and adults have cognitively efficient processes for number cognition, which have distinctive signature limits (Feigenson, Dehane & Spelke, 2004), so we should expect cognitively efficient processes for perspective-taking to be limited in their scope. In contrast, when adults are required to reason explicitly about perspectives we should expect their abilities to be limited only by limits on their general capacity for complex, effortful thought.

Secondly, there are good empirical reasons for supposing that some kinds of perspective-taking are significantly more demanding than others. Flavell and colleagues suggested that there were at least two developmental levels to visual perspective-taking (Lempers, Flavell, & Flavell, 1977; Masangkay, McCluskey, McIntyre, Sims-Knight, Vaughn & Flavell 1974; Flavell, Everret, Croft & Flavell, 1981; Flavell, Flavell, Green & Wilcox 1981). In particular, they characterised Level-

Level-1 perspective-taking as being the ability to interpret whether someone else can or cannot see a given object and Level-2 perspective-taking as understanding that “an object simultaneously visible to both the self and the other person may nonetheless give rise to different visual impressions or experiences in the two if their viewing circumstances differ” (Flavell, Everett, Croft and Flavell, 1981, p1). On traditional, direct measures of visual perspective-taking children pass Level-1 tasks around the age of 2-years (Moll & Tomasello, 2006), but do not pass similar Level-2 tasks till around the age of 4 or 5 (Flavell, Everett et al., 1981, Masangkay et al., 1974). Recent, indirect, measures have shown precocious perspective-taking abilities in infants (Onishi & Baillargeon, 2005; Sodian et al., 2007; Southgate et al., 2007; Surian et al., 2007) and non-human animals (Clayton & Emery, 2004; Hare, Call & Tomasello, 2001; Santos, Nissan & Feruggia, 2006). Interestingly, the Level-1/Level-2 distinction also describes these precocious abilities: many of these new tasks imply Level-1 perspective-taking, but as yet there is no positive evidence of the equivalent Level-2 ability.

In spite of the Level-1/Level-2 distinction forming a key part of our understanding of how children's perspective-taking abilities develop, Level-2 perspective-taking has received little attention in the literature on adults; although an interesting parallel literature on spatial perspective-taking has been fruitful (Kessler & Thomon, 2009; Michelon & Zacks, 2006). We therefore adapted Samson et al.'s (2010) task so that we could elicit Level-2, as well as Level-1 judgements, using the very same stimuli. Given the existing literature there was a clear prediction that when directly required to judge perspectives adults would show egocentrism for Level-1 and Level-2 judgements. Of equal interest was adults' performance on the indirect measure of

perspective-taking. Recall that Samson et al. (2010) found that when adults made Level-1 judgements about their own visual perspective they suffered interference from the irrelevant, incongruent perspective of the avatar in the scene. Samson et al. suggested that this interference provided an indirect measure of participants' tendency to compute the avatar's perspective automatically. The present studies investigated whether a similar effect would be apparent for Level-2 judgements.

Evaluating this indirect measure of perspective-taking requires care, because there are other reasons why adults might be slower and more error prone to judge their own perspective, and these need to be eliminated before it is possible to conclude that such interference results from automatic perspective-taking. Most obviously, unnecessary processing of the avatar's perspective during Self trials (where participants judged their own perspective) could simply be the result of carry-over effects from Other trials (where they were directly required to judge the avatar's perspective). Such carry-over effects would be evidence of involuntary, unnecessary processing of the avatar's perspective, but this would be a consequence of the task design, rather than evidence of automatic processing driven by the presence of the avatar stimulus (see e.g., Samson et al., 2010, for a discussion).

To provide a baseline against which findings from the perspective-taking conditions could be judged, separate groups of participants completed "self-projection" conditions. In these conditions participants viewed stimuli in which the avatar was replaced by a striped oblong block, but which were otherwise identical to the stimuli in the perspective-taking conditions (see Table 4.1). On "Self" trials, participants judged their own, current, perspective on the stimulus. These judgements were

identical to the ones participants made in the Self trials of the perspective-taking task, with the only condition difference being that the stimulus for judgement included an oblong block rather than an avatar. On “Other” trials, participants judged what their own perspective would be if they were positioned in the scene depicted in the stimulus, facing outwards, with their back against the oblong block. The contents of these judgements were identical to those in the Other trials of the perspective-taking tasks, but the agent to which they were ascribed was the imagined self (“I would see X”) rather than the avatar (“He sees X”). Altogether, the Level-1 and Level-2 self-projection conditions were highly analogous to the corresponding perspective-taking conditions, with the critical difference being that the presented stimuli did not contain an avatar that might cue automatic perspective-taking.

This design led to the following predictions. First, for both Level-1 and Level-2 judgements, and for both perspective-taking and self-projection conditions, the mere fact that participants made both Self and Other judgements might lead to interference effects, whereby judgement on any given trial might suffer interference from unintended computation of the alternative perspective. Moreover, if the only reason for such interference was carry-over effects between Self and Other judgements, then we would not expect any difference between the interference observed in perspective-taking conditions compared with self-projection conditions. However, if the presence of the avatar in the scene acts as a cue for automatic perspective-taking, then we have a second distinctive prediction: we should observe more interference in perspective-taking conditions, compared with the baseline of the self-projection conditions. Third, if automatic perspective-taking cued by the presence of the avatar only calculates Level-1 perspectives (as suggested by Apperly & Butterfill, 2009), then we should

observe more interference in the Level-1 perspective-taking condition compared with the Level-1 self-projection condition, but no difference between the interference observed in the two Level-2 conditions.

4.2 Experiment 3A: Level-1 Judgements

4.2.1 Method

In Experiment 3A, separate groups of participants made Level-1 judgements, either in the perspective-taking condition or in the self-projection condition. Participants made judgements about the number of letters seen in a given stimulus (see Table 4.1). For “Other” trials they judged how many letters could be seen by the cartoon avatar (in the perspective-taking condition) or how many letters they would see if they were standing against a striped block (in the self projection condition). For “Self” trials, participants in both the perspective-taking and the self projection conditions judged how many letters they could see. On Consistent trials, self and other perspective content was equivalent (all letters were in front of the avatar/block). For Inconsistent trials self perspective content was one greater than other perspective content: one of the letters was located behind the avatar/block. Previous studies using this paradigm have shown that interference effects are observed when the participant's privileged view includes up to 3 items (Samson et al., 2010).

4.2.1.1 Participants

Participants were 50 undergraduate or postgraduate students from the University of Birmingham (average age: 19.9 Years, 44 female) who participated for course credits or a small honorarium.

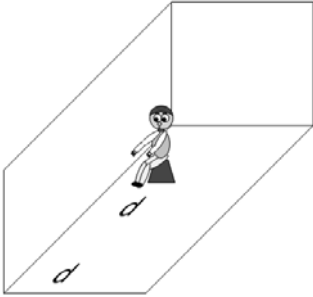
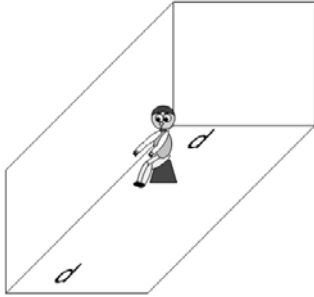
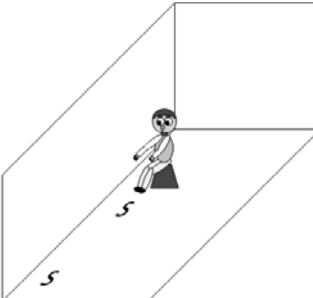
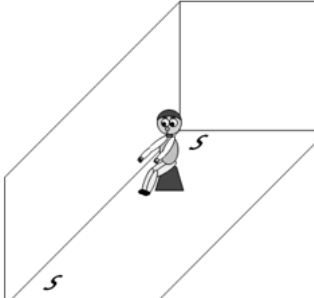
4.2.1.2 Design and Procedure

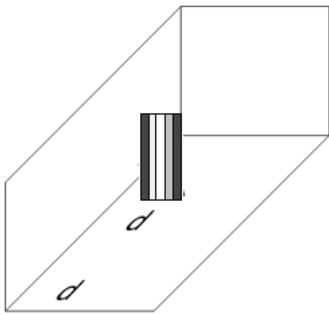
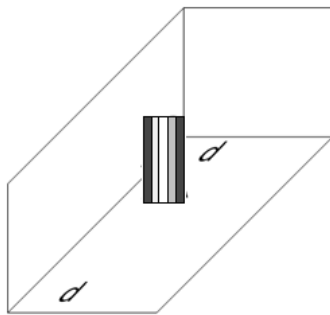
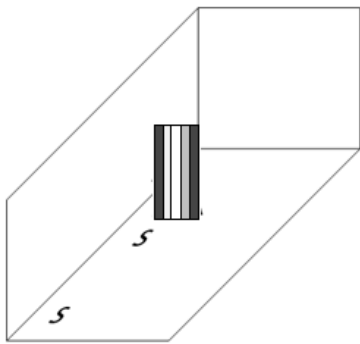
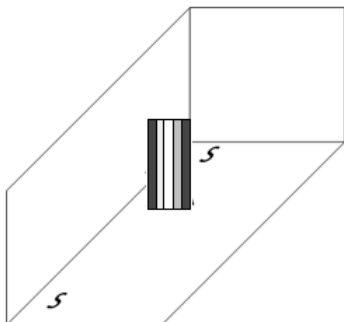
Participants were pseudo-randomly assigned to one of two conditions: perspective-taking or self projection. Participants completed the experiment in a testing cubicle. Instructions included detailed descriptions of the procedure and an instruction to respond as quickly and accurately as possible. Practice trials were completed until the participant had successfully answered a question for each of the four conditions (Self-Consistent, Self-Inconsistent, Other-Consistent and Other-Inconsistent).

On each trial, participants viewed successive fixation stimuli (a smiling face (600ms) and a fixation cross (600ms)) followed by a 1800ms auditory stimulus and then the test picture depicting an avatar in a room with 1-3 letters on the wall. For participants in the perspective-taking version of the task, this auditory stimulus was either "He sees X" or "You see X", whereas for participants in the self-projection version of the task the auditory stimulus was either "From block X", or "From here X". X was either "one", "two" or "three". Participants pressed one of two keys to indicate whether or not the auditory stimulus correctly described the picture. Response time was measured from the onset of the picture. Participants completed 288 test trials. These consisted of 144 experimental trials, and 144 trials used as filler trials to match the demands of a planned further experiment (Experiment 3B). Experimental trials used the letters p, r, u, n, m and w; filler trials s, z, o and x. In half of trials self and other perspectives

were consistent (36 Self, 36 Other) and in the others they were inconsistent (36 Self, 36 Other). In half of the trials the letters appeared on the side wall of the room, and in the rest they appeared on the floor. The experiment was presented on a computer using E-prime 2.0 (Psychology Software Tools, Inc.).

Table 4.1. Examples of trials forming the key contrasts in Experiment 3A. Note that the very same stimuli were used in both experiments. Letter stimuli were equally often on the wall and on the floor, with equal numbers of Consistent and Inconsistent trials in each case.

		Consistent	Inconsistent
Perspective-taking	Experimental		
	Filler		

Self-projection	Experimental		
	Filler		

4.2.2 Results

Self and Other trials were analysed separately, as we had no hypotheses about the relative size of any effects observed in these two conditions. Experimental and filler trials were entirely equivalent from a Level-1 perspective, and so filler trials could, in principle, have been analysed here. However, we excluded filler trials in order to have equivalent statistical power in Experiments 3A and 3B. Importantly, the patterns of performance on experimental and filler trials did not differ, and the effects shown here are replicated in an analysis of the complete data set.

4.2.2.1 Direct Measure of Perspective-taking

Examining the effect of perspective consistency on Other trials allowed us to test for egocentric interference using a direct measure. In calculating average response times, data points that were more than 2.5 standard deviations from the mean were excluded (3.1% for the perspective-taking condition and 8.7% for the self projection condition), as were data from incorrect responses. Excluding data using more (2 standard deviations) or less (3 standard deviations) strict criteria did not change any of the significant findings reported. To gain a single indication of participants' performance, processing cost was calculated by dividing each participant's average response time for each condition by the proportion of correct answers made by that participant in that condition (such a measure incorporates any speed/accuracy trade off made by individual participants). Appendix 1 shows Response Times and Accuracy data independently.

An ANOVA with Consistency (Consistent, Inconsistent) as a within subjects factor, and Condition (Perspective, Projection) as a between subjects factor revealed an effect of Consistency ($F(1, 49) = 36.53, p < .001, \eta p^2 = .43$, Inconsistent > Consistent) and an effect of Condition ($F(1, 49) = 4.18, p = .046, \eta p^2 = .080$, Projection > Perspective). The interaction between Consistency and Condition was not significant ($F(1, 49) = .48, p = .49, \eta p^2 = .010$).

On this direct measure of perspective-taking there was clear evidence of egocentric interference. Although participants responded significantly more quickly to perspective-taking than self projection trials, the egocentric interference did not differ in the two conditions.

4.2.2.2 *Indirect Measure of Perspective-taking*

Examining the effect of perspective consistency on Self trials allowed us to indirectly test whether the avatar's perspective was processed automatically in the perspective-taking condition, leading to interference with judgements about Self perspective. Outliers were excluded on the same basis as in the direct perspective-taking trials (1.6% of data considered an outlier in the perspective-taking condition and also 1.6% in the projection condition).

An ANOVA with Consistency (Consistent, Inconsistent) as a within subjects factor, and Condition (Perspective, Projection) as a between subjects factor revealed an effect of Consistency ($F(1, 49) = 89.88, p < .001, \eta p^2 = .65$, Inconsistent > Consistent). There was no main effect of Condition ($F(1, 49) = .11, p = .74, \eta p^2 = .002$). The interaction between Consistency and Condition was found to be significant ($F(1, 49) = 4.12, p = .048, \eta p^2 = .079$). Post-hoc t-tests showed the effect of Consistency to be significant for both Perspective-taking ($t(24) = 6.94, p < .001$, Inconsistent > Consistent) and Self Projection ($t(24) = 6.68, p < .001$, Inconsistent > Consistent), but critically, the effect of Consistency was greater for the Perspective-taking condition.

Consistent with Samson et al. (2010) our indirect measure identified interference from the other task when making Self judgements, reflected in a main effect of Consistency. Importantly, however, the interaction between Condition and Consistency was also significant. That is to say, participants suffered more interference from irrelevant calculation of the avatar's perspective than from irrelevant calculation of what they themselves would see if they projected themselves into the position of the block in the scene.

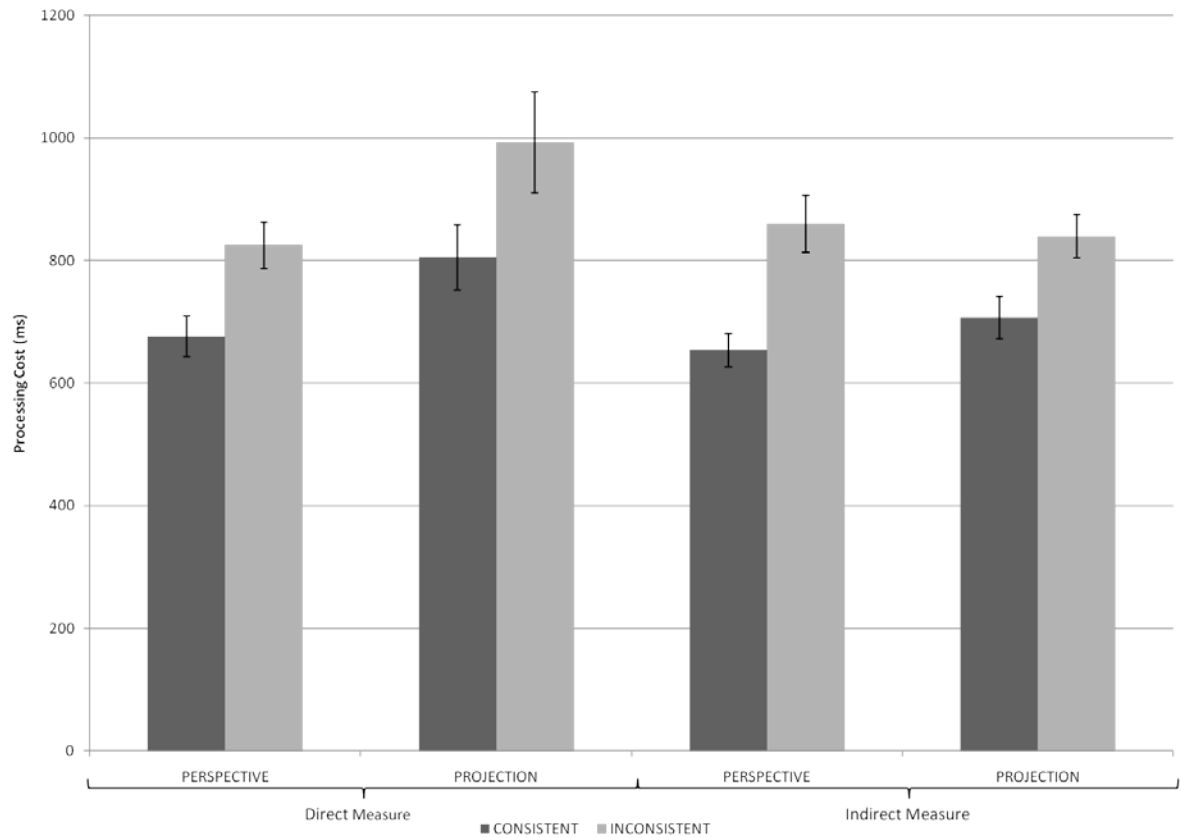


Figure 4.1. Mean processing costs for Experiment 3A. Error bars represent the standard error of the mean.

4.3 Experiment 3B

4.3.1 Method

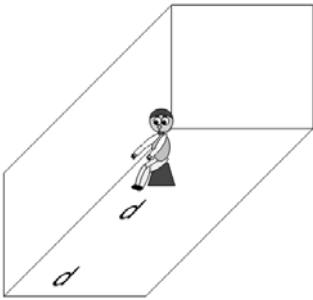
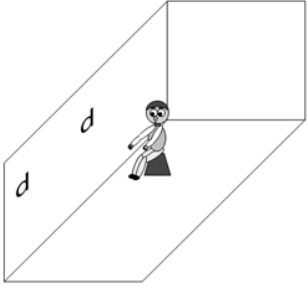
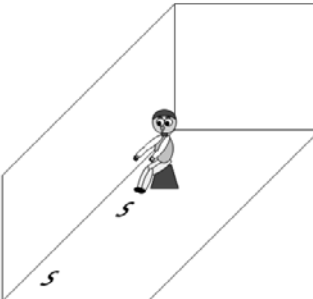
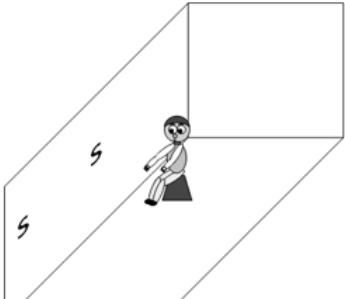
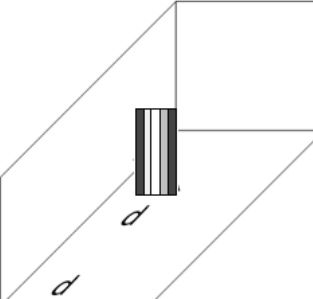
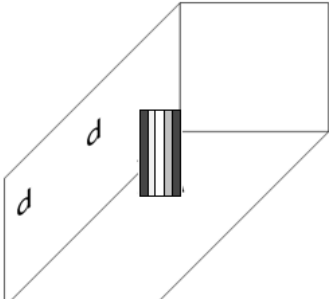
4.3.1.1 Participants

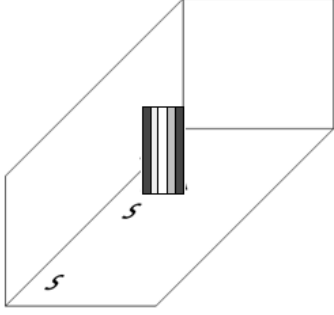
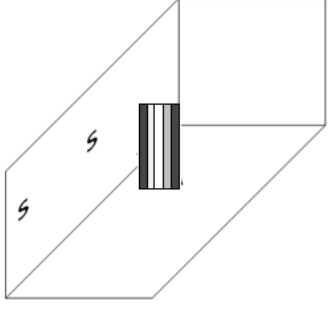
Participants were 50 undergraduate or postgraduate students from the University of Birmingham (average age: 20.3 Years; 46 female) who participated for course credits or a small honorarium.

4.3.1.2 Stimuli and procedure

The method for Experiment 3B was equivalent to that used in Experiment 3A except that judgements were made about the nature of the letters that could be seen, rather than just the number that were visible. Self judgements always required the participant to judge which letter(s) they could see. For the “Other” condition participants either judged which letter the avatar could see or which letter they would see if they, themselves, were stood against the block. The crucial design feature of the stimuli was that in experimental trials, the letters were rotational pairs ({m, w}, {n, u} and {p, d}). In stimuli with letters on the wall of the room (Consistent trials), they appear as the same letter to self and “other”; in stimuli with the letter(s) on the floor of the room (Inconsistent trials), they present as different letters to self and “other”. To test for any confounding effect of location of the letter, participants also viewed control stimuli which appeared equivalent in both locations (s, o, z, x). Participants completed 144 experimental trials (36 Self-Consistent, 36 Self-Inconsistent, 36 Other-Consistent, 36 Other-Inconsistent) and 144 matched control trials.

Table 4.2. Examples of trials forming the key contrasts from Experiment 3B. All trials displayed here are “Consistent” for Level-1 perspective judgements, but since the entire stimulus set was the same as that used for Experiment 3A, an equal number of stimuli were “Inconsistent” from a Level-1 perspective.

		Consistent	Inconsistent
Perspective-taking	Experimental		
	Control		
Self-projection	Experimental		

	Control		

4.3.3 Results

4.3.3.1 Direct Measure of Perspective-taking

4.3.3.1.1 Experimental trials

Response time outliers were excluded in the same way as for Experiment 3A (3.9% of data for perspective-taking and 4.8% for self projection), as were data from incorrect responses. Again the dependent variable used was a measure of processing cost, corresponding to mean response time divided by proportion correct for each condition for each participant.

An ANOVA with Consistency (Consistent, Inconsistent) as a within subjects factor and Condition (Perspective, Projection) as a between subjects factor revealed an effect of Consistency ($F(1, 49) = 11.51, p = .001, \eta p^2 = .193$, Inconsistent > Consistent) and an effect of Condition ($F(1, 49) = 9.46, p = .003, \eta p^2 = .17$, Projection > Perspective). The interaction between Consistency and Condition was not significant ($F(1, 49) = .14, p = .71, \eta p^2 = .003$).

4.3.3.1.2 *Control trials*

A similar ANOVA on control trials with Stimulus Location (Wall, Floor) as a within subjects factor and Condition (Perspective, Projection) was completed. Note that the factor "Stimulus Location" manipulates the location of the letters in just the same way as the factor "Consistency" in experimental trials, but it has no effect on perspective consistency since the letters in control trials appeared the same in both wall and floor locations. Therefore, control trials allowed us to check whether the mere location of the letter stimuli had a significant effect on participants' performance. There was an effect of Condition ($F(1, 49) = 5.33, p = .025, \eta p^2 = .10$, Projection > Perspective), but no main effect of Stimulus Location ($F(1, 49) = 2.65, p = .11, \eta p^2 = .052$), and no interaction ($F(1, 49) = 2.07, p = .16, \eta p^2 = .018$). This confirmed that the location of the stimulus items on the floor or the wall did not itself have any effect on participant's performance, suggesting that the effect of Consistency observed on Experimental trials was genuinely due to whether or not self and other perspectives were consistent.

4.3.3.2 *Indirect Measure of Perspective-taking*

4.3.3.2.1 *Experimental trials*

In calculating average response times, data were excluded in the same way as for Other trials (3.9% of data for perspective-taking and 4.8% for self projection), as were data from incorrect responses.

An ANOVA with Consistency (Consistent, Inconsistent) as a within subjects factor and Condition (Perspective, Projection) as a between subjects factor revealed an effect of Consistency ($F(1, 49) = 40.00, p < .001, \eta p^2 = .46$, Inconsistent > Consistent) and a

trend towards an effect of Condition ($F(1, 49) = 3.28, p = .076, \eta p^2 = .064$, Projection > Perspective). The interaction between Consistency and Condition was not significant ($F(1, 49) < 0.001, p > .99, \eta p^2 < .001$). The absence of this interaction indicates that the effect of Consistency was no greater for the Perspective condition than for the Projection condition.

4.3.3.2.2 *Control trials*

A similar ANOVA on control trials revealed no main effect of Stimulus Location ($F(1, 49) = .004, p = .95, \eta p^2 < .001$), again a trend towards an effect of Condition ($F(1, 49) = 3.45, p = .070, \eta p^2 = .067$, Projection > Perspective) and no interaction ($F(1, 49) = 2.07, p = .16, \eta p^2 = .041$).

For the Level-2 tasks, there was an effect of the consistency of stimuli for experimental trials (there was a cost in making judgements about stimuli which could be viewed differently from the alternative perspective). As with Experiment 3A, directly taking the perspective of another was easier than projecting oneself into an imaginary position in space. However, in contrast to Experiment 3A, there was no interaction between Condition and Consistency. That is to say, participants in Experiment 3B suffered no more interference from irrelevant calculation of the avatar's perspective than from irrelevant calculation of what they themselves would see if they projected themselves into the position of the block in the scene.

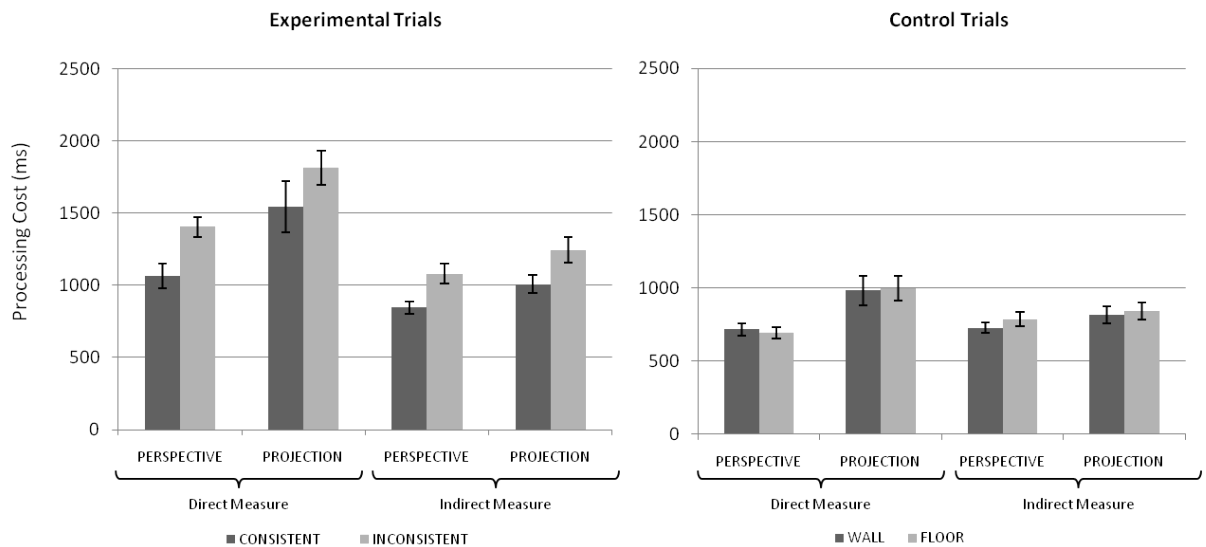


Figure 4.2. Mean processing costs for Experiment 3B. Error bars represent the standard error of the mean.

4.4 Discussion

In two experiments we investigated the processing costs incurred when adults make different kinds of perspective-taking judgements, either judging an alternative perspective or their own self-perspective. There were three main findings. First, when participants were directly asked to adopt an alternative perspective they showed significantly greater processing costs when the alternative perspective was their own projected self rather than an avatar that was physically present in the stimulus. Second, all direct judgements of an alternative perspective incurred a higher processing cost when the alternative perspective was inconsistent with the participant's own, current self-perspective. Third, when participants judged their own, current self-perspective they showed higher processing costs when the irrelevant alternative perspective was inconsistent, and this effect was particularly marked when participants made Level-1 self-perspective judgements with the avatar physically present in the stimulus. We discuss each of these effects in more detail below.

4.4.1 *Directly assessing the perspective of others: An effortful process*

Effects of perspective consistency when participants made direct judgements about an alternative perspective fit with previous reports that adult participants show egocentric biases (Keysar et al., 2003; Epley et al., 2004, Michelon & Zacks, 2006; Samson et al., 2010) and add to evidence that such bias is pervasive across different kinds of perspective judgement. Importantly, though, egocentric biases are consistent with at least two perspective-taking strategies. Firstly, participants could be using a strategy of egocentric anchoring and adjustment (Epley et al., 2004), initially representing a self-perspective and making a series of adjustments away from this. Specifically relating to our paradigm, an egocentrism and adjustment hypothesis would suggest that Consistent trials are processed more efficiently because self perspective already represents an appropriate estimate of other-perspective, and so effortful adjustments are not required. However, anchoring and adjustment is not the only strategy available for working out what someone else may see. For example, to make a Level-1 judgement about the avatar's perspective in the stimulus in the top right hand panel of Table 4.1, participants could employ a strategy of judging how many items appear in front of the avatar, rather than beginning with the thought that "He sees 2" based on their own self-perspective and adjusting away from this on the basis of what the avatar cannot see. Participants may nonetheless show egocentric effects because their self-perspective is a salient distracter, with the potential for interference being greater when self-perspective is inconsistent with the other perspective to be judged. It is not possible to distinguish between these alternative accounts for the current data, but evidence that insufficient adjustment away from an egocentric anchor is not the only source of such effects comes from a study by Apperly, Back, Samson and France (2008) who found interference between self and other perspectives even when

participants did not need to infer someone else's perspective because they were simply told what the other person thought.

Our self-projection condition, included for comparison with direct other perspective-taking, showed two interesting effects. Firstly, egocentric interference here was as strong as in the perspective-taking conditions, showing that explicitly social paradigms are not required to illustrate egocentric-type effects (Gopnik & Astington, 1988; Perner & Leekam, 2008; Surtees & Apperly, in press, Chapter 2). Secondly, imagining an alternative self perspective was more difficult than simply taking another's perspective. Whilst taking another's perspective is effortful, and possibly requires rotating one's own perspective (Kessler & Thomson, 2010; Kozhevnikov & Hegarty, 2001; Michelon & Zacks, 2006), it seems to be easier than imagining oneself into a different spatial position. A potential explanation for this effect comes from Kessler and Thomson (2010), who found that participants were better at judging the spatial perspectives of others when their own posture matched the posture of the other. Given these findings, one interpretation of our results would be that the lack of a bodily form to project into in our self-projection condition makes these judgements more difficult than the perspective-taking condition.

4.4.2 Automatic Level-1 perspective taking

Not all perspective-taking is effortful. The indirect measure of perspective-taking in the current study provides converging evidence to Samson et al.'s claim that Level-1 perspectives may be calculated automatically, and extends the evidence base for this effect. Firstly, in the original method employed by Samson et al. (2010) (also, Surtees & Apperly, in press, Chapter 2), participants always viewed the avatar side-on,

meaning that the avatar's direction of view was perpendicular to the participant's. In the current method, participants always viewed the avatar head-on. This suggests that automatic processing of the avatar's perspective is not specific to the stimuli used by Samson et al., and can be cued by a variety of views of the avatar. Secondly, the baseline condition we used was unique. Samson et al. (2010) found that participants who judged their own perspective experienced interference from the irrelevant perspective of the avatar, but experienced no such interference in a baseline condition in which the avatar was replaced with a featureless oblong stick. The current study found that even when Level-1 perspective-taking is compared with a closely-matched self-projection condition, participants experienced significantly greater interference when judging their own perspective in the perspective-taking condition. This indicates that, over and above interference due to carry-over between self and other judgements made between trials (which was present in both perspective-taking and self-projection conditions), the presence of an avatar in the perspective-taking condition generated further interference. Following Samson et al. (2010) we suggest that this interference arose from automatic computation of the avatar's perspective.

4.4.3 The Level-1/ Level-2 distinction as a limit on efficient Theory of Mind

In contrast to the findings with Level-1 perspective-taking, in Experiment 3B Level-2 perspective-taking did not show greater interference on participants' judgements of their own perspective than our self projection condition. If we suppose that the interference effects on self judgements observed by Samson et al. (2010) and in Experiment 3A are due to automatic calculation of the avatar's perspective, then Experiment 3B suggests that this automatic process may only support Level-1 perspectives, and not Level-2 perspectives. Clearly, this does not preclude the

possibility that under other circumstances Level-2 perspectives *can* be computed automatically, but to date there is no evidence from adults to suggest that this is possible.

The potential importance of the Level-1/Level-2 distinction as a “signature limit” to efficient perspective-taking is that it helps explain converging evidence from very different participant groups on very different paradigms, which indicates that participants with limited cognitive resources may be able to take Level-1 perspectives, but not Level-2 perspectives. Tasks using preferential looking or violation of expectation paradigms have demonstrated Level-1 abilities in infancy, but so far there is no evidence of Level-2 abilities (Onishi & Baillargeon, 2005, Sodian et al., 2007, Southgate et al., 2007, Surian et al., 2007). Children from 2-years of age, but not 18 months, have made explicit solutions requiring Level-1 perspective-taking (Moll & Tomasello, 2006), but again there is no evidence of such success in a Level-2 paradigm until around the age of four (Flavell et al., 1981). On similar tasks to those employed by Moll and Tomasello (2005), non-human animals have also shown precocious abilities for Level-1 perspectives (Clayton & Emery, 2004; Hare et al., 2001, Santos et al., 2006), but not for Level-2 perspectives. We thus follow Apperly and Butterfill (2009) in suggesting that there is strong evidence to suggest that as a general rule Level-2 perspective-taking tends to require controlled processing, which comes at a cost to efficiency.

4.4.4 Conclusion

We propose then, that there are two qualitatively distinct routes to perspective-taking: one route requires deliberate and effortful adjustments to the perspective of other.

This is the route identified by traditional methods of testing perspective-taking abilities. Effortful and controlled processing affords flexibility, and for this reason this route supports both Level-1 *and* Level-2 judgements, and we suggest that there is currently no evidence that Level-2 perspective-taking can be achieved in any other way. Whilst affording flexibility, this comes at a cost to processing efficiency, due at least in part to interference from one's own perspective. One open question is whether this cost is the result of participants *using* their own perspective in obtaining starting conditions for a representation of the perspective of other (in line with egocentric anchoring and adjustment; Epley et al., 2004), or if the cost comes from the need to inhibit a self-perspective in order to calculate or select another perspective. A second route to perspective-taking is automatic in the sense it operates outside of cognitive control and relatively effortless in the sense that it is not disrupted by a secondary executive task (Qureshi, Apperly & Samson, 2010). Such a route has only been identified through indirect measures. Whilst this route is efficient, it does not afford flexibility, and limits, such as the Level-1/Level-2 distinction constrain the performance of this route. So far there is no evidence that this route supports explicit judgements of the perspectives of others.

4.5 *Summary and Links to Chapter 5*

Chapters 2-4 have investigated visual perspective-taking in children and adults using both direct and indirect measures. Much of the focus has been on the indirect measures gained from this study: concluding in the suggestion that an efficient route to perspective-taking exists for both children and adults, but that it is limited by a signature limit that can be approximated to the Level-1/Level-2 distinction.

When looking at the results from the direct measures of perspective-taking used, every measure, at every age group, has identified egocentric interference. It seems clear that when older children and adults complete even simple tasks, those passable by young children from the age of 2-4, they suffer a cost to ignoring their own perspective on the world. What seems crucial in being a successful perspective-taker is the ability to put one's own perspective to one side. In the past individual differences in the emergence of ToM have been related to the executive functions. New paradigms allow for the investigation of whether further developments in ToM are related to the executive functions (Dumontheil et al., 2010; Apperly et al., in press). The following chapter investigates whether individual differences in egocentrism, an ability so crucial in interpreting the minds of others, is also related to the executive functions in children aged 5-7.

CHAPTER 5

The role of executive functions in theory of mind in middle childhood

The following, largely in its current form, has also been submitted as the article:

Surtees, A. D. R., Burns, P., Beck, S. R., Riggs, K. J. & Apperly, I. A. (submitted),

The role of executive functions in theory of mind in middle childhood

5.0 Abstract

The relationship between Theory of Mind (ToM) and executive function is well established. The vast majority of research on this relationship, however, has focussed on one specific age group (pre-school children) and one specific measure of ToM (the false belief task). ToM is thought to undergo a protracted development and encompass a range of different abilities. It is, therefore, important to identify whether executive abilities underpin development in ToM after the age of 4 and also whether executive abilities predict performance in a range of different ToM tasks. The current study addressed both of these issues, testing children aged 5-7 (N=57) on a range of ToM and executive function measures. Children's egocentrism in visual perspective-taking was predicted by a measure of inhibition and a measure of task switching. Children's ability to reason about false beliefs was correlated to a measure of less complex inhibition and to their memory span, though these relationships with false belief were not substantiated in a regression analysis. We suggest that executive function and ToM do continue to be related once initial concepts of belief, desire and perspective are in place, but that in different age groups distinct executive abilities may prescribe individual difference in separate ToM tasks.

5.1 Introduction

Taking the perspectives of other people is an important part of everyday social interaction. Three very different forms of perspective-taking involve Visual Perspective-taking, Referential Communication and Belief-Desire reasoning. Such varied forms of social cognition are thought to form part of the broader concept of Theory of Mind (ToM). The vast majority of research on ToM has focussed on the performance of young children, who fail seemingly simple problems up till at least the

age of four (Wimmer & Perner, 1983; Wellman, Cross & Watson, 2001). Across all these tasks young children commonly make egocentric errors: errors made do not reflect a random approach to responding, but rather one in line with an over-application of self perspective (Piaget & Inhelder, 1956; Wimmer & Perner, 1983). Success in these tasks is commonly found to be linked to individual differences in executive functions (Carlson & Moses, 2001; Hughes & Ensor, 2007).

Within this narrow age group, the investigation of false beliefs has received the majority of attention (Bloom & German, 2000), but there is also good evidence about the abilities of young children in simple perspective-taking (Flavell, Everett, Croft & Flavell, 1981; Moll & Tomasello, 2006) and referential communication (Nadig & Sedivy, 2002). Whilst such processes are often thought to make similar demands, and some of these develop at similar times (Masangkay, McCluskey, McIntyre, Sims-Knight, Vaughn & Flavell, 1974; Nilsen & Graham, 2009; Wellman et al., 2001), there is little evidence that those who are fluent in one of these abilities are necessarily more fluent in other such abilities. In separate studies, different aspects of ToM have been linked to executive functions in different age groups. Most commonly, studies have looked at correlations between individual differences in belief-reasoning and executive functions in childhood (Carlson & Moses, 2001; Hughes & Ensor, 2007). This link is not restricted to belief reasoning: Nilsen and Graham (2009) found young children's executive abilities to also correlate with performance on a referential communication task that required them to take account of the speaker's visual perspective. This link between ToM and executive function is also not restricted to childhood: there is good evidence that older adults' executive abilities predict performance deficits in ToM tasks (German & Hehman, 2006) and

that young adults perform poorly under dual task conditions (Bull, Phillips & Conway, 2008). The distinctive features of the current study are that it examines the relationship between several ToM tasks, as well as the relationship between these tasks and tests of executive function, and it does so in a sample of 5- to 7-year-old children who pass many standard assessments of ToM.

When adults are presented with tasks where they have to make estimates of others' judgements, a range of studies have found them to suffer from egocentric biases (Bernstein et al., 2004; Nickerson, 1999; Royzman et al., 2003). More recently, new paradigms have also shown that adults have limits to their ToM, suffering egocentric costs on belief reasoning (Apperly, Warren, Andrews, Grant & Todd, in press), referential communication (Keysar, Lin & Barr, 2003) and Level-1 perspective-taking tasks (Samson, Apperly, Andrews & Bodley-Scott, 2010). These studies suggest that for both children and adults ToM tasks where participants make explicit responses require effortful processing to overcome egocentric biases. Studies using similar paradigms have shown significant advancements in performance in middle childhood (Dumontheil, Apperly & Blakemore, 2009; Surtees & Apperly, in press, Chapter 2). As children get older they become more efficient at this effortful processing, but there has, as yet, been no direct investigation of what underpins this development. The current paper explores the hypothesis that these developments in ToM are underpinned by developments in executive function.

The executive functions are a set of diverse cognitive abilities often found to recruit areas of frontal cortex (Collette et al., 2005; Hwang, Velanova & Luna, 2010; Luria, 1973; Miller & Cohen, 2001). They allow for the planning, coordinating and

implementation of complex thinking and behaviour. In particular, the executive functions allow us to enact complex cognition on the basis of abstract rules and to flexibly switch between such rules. Whilst there has been debate about how to structure the different aspects of executive function, some agreement supports splitting executive functions into three related, but distinct components: Inhibition, Task Switching and Working Memory (Collette et al., 2005; Diamond, 2006; Fisk & Sharp, 2004; Miyake et al., 2000). Inhibition constitutes the ability to ignore a pre-potent response in favour of enacting a rule-based response, task switching the ability to flexibly switch between two abstract rules and working memory the ability to hold in mind and update information when carrying out a task.

Like ToM, much of the focus of developmental psychologists on the executive functions has been on very young children. Typically pre-school children find it very difficult to inhibit pre-potent responses (Kochanska et al., 1996), to switch between different abstract rules (Espy, 1997; Kirkham, Cruess & Diamond, 2001) and have very limited abilities in working memory (Diamond & Goldman-Rakic, 1989). Interestingly though, like ToM, recent evidence has shown that the Executive Functions continue to develop into middle childhood (Cepeda, Kramer & de Sather, 2001; Davidson, Amso, Anderson & Diamond, 2006; Gathercole, 1999; Gathercole, Pickering, Ambridge & Wearing, 2004).

Studies with young children have tested the relationship between ToM and the executive functions by investigating links between individual differences in each of these constructs (Carlson & Moses, 2001; Carlson, Moses, & Breton, 2002; Carlson, Moses, & Claxton, 2004; Hughes 1998a, 1998b; Hughes & Ensor, 2007; Moses,

2001; Perner & Lang, 1999; Rakoczy, 2010). As well as showing consistent correlations between ToM and both inhibition and working memory, longitudinal studies have shown that earlier executive abilities predict later ToM performance, but that the reverse is not the case (Carlson et al., 2004; Hughes & Ensor, 2007). In fact, Carlson et al (2004) showed that executive abilities tested at an earlier age (2 years) showed a stronger correlation with ToM at the age of four than executive abilities tested at the very same time.

Whilst both working memory and inhibition have been found to be related to performance on false belief tasks, it is widely believed that it is inhibition that has the most important relationship. The correlation between inhibition and belief reasoning survives controlling for working memory (Carlson et al., 2004), as well as a whole host of other factors that could be thought to account for the relationship, whilst working memory no longer significantly correlates with inhibition if inhibition is controlled for. Interestingly, though, the best predictor of performance on ToM tasks seems to be performance on conflict inhibition tasks, which are thought to implicate a joint inhibitory and working memory load (Moses, 2001).

In spite of the fact that the relationship between the executive functions and ToM in young children is strongly established and well-defined, it is limited. Specifically, it is limited to describing the relationship at a given point in development. This is not such a severe limitation if ToM and Executive Function are fully established during this period. There is, however, clear evidence that both performance in ToM (Apperly et al., in press; Dumontheil et al., 2009; Surtees & Apperly, in press, Chapter 2) and Executive Functions (Burns, Riggs & Beck, submitted; Davidson et al., 2006;

Simpson & Riggs, 2005) undergo significant developments after the age at which all this evidence has been collected. There is no a priori reason to assume that those aspects of executive function that provide the limiting factors in the ToM abilities of a four year old will necessarily be the same limiting factors on the performance of older children. The current study is the first to test whether this is the case across a broad range of ToM tasks. We introduce each of these tasks below.

5.1.1 Belief-Desire Reasoning

Belief-Desire reasoning is by far the most studied subset of reasoning about mental states (Friedman & Leslie, 2004; Wellman et al., 2001; Wimmer & Perner, 1983). In particular the paradigmatic case of false beliefs is an area well examined by developmental psychologists. In classic false belief tasks children must put aside their own knowledge of the world to judge what an ill-informed third person will do. Typically, children are not able to make correct responses to these tasks until around the age of four (Wellman et al., 2001; Wimmer & Perner, 1983). This effect survives many variations in presentation format and across cultures (Wellman et al., 2001). Reasoning about True Beliefs and conflicting desires develops somewhat earlier (Friedman & Leslie, 2004). Correlations between false belief performance and executive function measures are very clear in the extent that they show a relationship between the two factors (Carlson & Moses, 2001; Carlson et al., 2002; Carlson et al., 2004; Hughes 1998a, 1998b; Hughes & Ensor, 2007; Moses, 2001; Perner & Lang, 1999; Rakoczy, 2010). Correlations are commonly found between False Belief performance and both Inhibition and Working Memory (Carlson & Moses, 2001; Carlson et al., 2002; Carlson, et al., 2004; Hughes 1998a, 1998b; Hughes & Ensor, 2007; Moses, 2001; Perner & Lang, 1999). Such correlations between ToM and

executive functions are not limited to young children: German & Hehman (2006) found adults' belief reasoning to be predicted by measures of processing speed and inhibition. In particular, decline in belief-reasoning in adults was attributed to a decline in executive abilities.

Whilst varying the veracity of a target's belief has received more attention in the literature, it is also possible to vary the nature of an individual's desire for a given object. If a person holds an approach desire, they wish to select a location in which a specified item is found. If they hold an avoidance desire they wish to avoid this location (Leslie & Polizzi, 1998). Neither avoidance desires nor approach desires conflict necessarily with reality, but children are generally found to successfully reason about approach desires before avoidance desires (Leslie, German & Polizzi, 2004; Leslie & Polizzi, 1998). Leslie et al. propose that tasks that combine false beliefs with avoidance desires are particularly difficult as they place additive demands on inhibitory resources.

For the current study we used a measure of Belief Desire reasoning developed by Apperly et al. (in press). In this task, children make multiple judgements under time pressure about the actions of a character who explicitly tells them of his beliefs and desires. Apperly et al. (in press) found evidence of egocentrism persisting beyond early childhood, with adult participants responding more slowly and less accurately when a character's belief was incorrect. As well as this, a similar effect was found in desire reasoning: participants were slower and less accurate when reasoning about avoidance desires than approach desires.

5.1.2 *Referential Communication*

When communicating with other people our view of the world does not necessarily match that of the person we are trying to communicate with. Normative communication should reflect this with speakers varying the content of their speech to suit the perspective of the listener, and listeners interpreting content on the basis of their knowledge as to the perspective of the speaker (Sperber & Wilson, 1986). Referential communication tasks (Horton & Keysar, 1996; Keysar et al., 2003) measure this ability through creating a perspective difference between the participants and someone who they are communicating with. Such tasks have found that interpreting communication in terms of a speaker's knowledge comes at a cost (Keysar et al., 2003).

Early studies of this ability in children suggested that children younger than 6 or 7 fail to successfully take into account the perspectives of others (Deutsch & Pechman, 1982; Lloyd, Mann & Peers, 1998). More recently, though, evidence has suggested that children as young as two years of age do show some evidence of tailoring their communication towards the perspectives of others and interpreting others in this way (O'Neill & Topolovec, 2001). What is clear, though, is that children are far from achieving fully accurate performance: Dumontheil et al. (2009) show children up to the age of 9 making errors on 70% of trials requiring them to take into account the perspective of another. When task demands are reduced by using a very small set of objects there is some evidence of improved performance, but children are still far from perfect (Nadig & Sedivy, 2002). A correlational study has shown this kind of ToM is also related to executive functioning (Nilsen & Graham, 2009). In particular,

as with belief reasoning, referential communication was related to inhibition (and in particular conflict inhibition) over and above working memory.

For our current study our test of referential communication was a computerised version of the task originally used by Keysar et al. (2003) and adapted by Dumontheil et al. (2010) and Apperly et al. (2010). In this task participants have to respond to the instructions of a director in a way that takes into account that the director cannot see all of an array. All studies using this paradigm have shown both children and adults to suffer egocentric interference from their own perspective, with the result that items only visible to the participant were often considered possible referents.

5.1.3 Level-1 Visual Perspective-taking

Level-1 visual perspective-taking (VPT) is defined by Flavell and colleagues to be the ability to non-egocentrically interpret whether or not someone else can see a given object (Flavell et al., 1981). It differs from Level-2 perspective-taking in not requiring the ability to represent *how* someone sees a given object/objects. Level-1 VPT tasks contain all the basic requirements of ToM: the requirement to assume the viewpoint of another, the ability to put one's own perspective to one side and the ability to respond in a way that reflects this. There is good reason, however, to think that Level-1 perspective-taking may not be so demanding of executive resources. Children pass these tasks around 2-years of age (Moll & Tomasello, 2006), a full two years before most explicit measures find evidence of ToM abilities (Wellman et al., 2001), including well-matched Level-2 VPT tasks (Masangkay et al., 1974).

For this study we adapted the task used by Samson et al. (2010; Qureshi, Samson & Apperly, 2010; Surtees & Apperly, in press, Chapter 2). In this paradigm, participants judge the perspective of another when it is either congruent or incongruent with their own.

5.1.4 The current study

We tested 5-7 year old children on a battery of executive function measures and a battery of ToM measures. In particular we tested children's abilities in Belief-Desire reasoning, Referential Communication and Level-1 Visual Perspective-Taking, alongside measures of Inhibition, Task Switching and Working Memory. Each ToM measure provided a measure of egocentrism, whilst belief-desire reasoning also provided a measure of avoidance desire reasoning.

If individual differences in ToM and the executive functions maintain a similar relationship as has been shown in young children, in our experiment, egocentrism should be related across the different ToM tasks, and they should all be related to inhibition. In particular, those complex forms of inhibition most likely to recruit task switching and working memory as well as inhibition should be most strongly correlated with ToM. Also, one might predict our measure of belief-desire reasoning to correlate with working memory as has also been shown in young children in the past. However, were the relationship between executive functions and ToM to accurately mirror that found in younger children, we should expect memory to no longer predict egocentrism if inhibition were controlled for.

5.2 EXPERIMENT 4

5.2.1 Method

5.2.1.1 Participants

Participants were fifty seven 5-7 year-olds from a school in Birmingham (average age: 6 years and 8 months, 32 female). These included 29 children from a year 1 class (second formal year of schooling) ($M = 6;4$ years, $SD = 3.3$ months) and 28 children from a year 2 class (third year of formal schooling) ($M = 7;3$ years, $SD = 3.5$ months). The participants came from a variety of ethnic backgrounds; however, the majority (74%) were white Caucasian. Performance on the British Picture Vocabulary Scale (BPVS) was within the standard range: Standardised Mean: 102.54 (Standard Deviation: 9.167).

5.2.1.2 Design

Children were tested in two sessions by two experimenters. In the first session, participants completed a battery of Executive Functions (EF) tasks (Burns et al., submitted). On a following day participants completed a battery of ToM measures.

The EF tasks were completed in a fixed order: Working Memory (a counting recall task based on Alloway, Gathercole, Willis & Adams, 2004; Burns et al., submitted), a task of Inhibition (complex) and Task Switching (Davidson et al., 2006), Inhibition (simple) and finally Memory span (Davidson et al., 2006).

The ToM tasks were also completed in a fixed order: Level-1 Visual Perspective-Taking (Samson et al., 2010; Surtees & Apperly, in press, Chapter 2), Referential Communication (Dumontheil et al., 2009; Keysar et al., 2003) and finally Belief-Desire reasoning (Apperly et al., in press).

5.2.1.3 Materials and Procedure

5.2.1.3.1 EF measures

Executive function tasks were the same as those used in another study (Burns, Beck & Riggs, submitted). All of the EF measures were presented on a laptop computer using E-prime 2.0 (Psychology Software Tools, Inc.). In three of the tasks (Eyes, Pictures, Span) participants responded using two custom built button boxes, in Counting Recall responses were verbal. The button boxes were made of plastic and had a surface area of 12 x 14 cm and a depth of 3.5 cm at the back sloping to 2.5 cm at the front. A circular plastic button with a 2.5 cm diameter button was situated in the upper middle of the box. For every task children were given specific instructions and a set of practice trials with success criteria.

Counting Recall. Counting Recall is a measure of Verbal Working Memory (Alloway et al., 2004). This task involved participants counting red circles in an array comprising these, and distracter blue squares. Children had to relay to the experimenter the number of circles they had seen on a series of such slides. For example, seeing a slide with 6 red circles, followed by one with 7, followed by one with 5, a correct answer would be 6, 7, and 5. Trials were presented in blocks of six. In the first block, children simply counted and remembered the number of red circles on a single slide. Subsequent blocks increased difficulty by requiring children to

remember the number of circles on a greater number of slides. Children progressed to subsequent blocks provided they responded correctly to four out of 6 trials. Scores for working memory are the total number of correct answers given by each child. The test retest reliability of counting recall is .74 among 5 to 8-year-olds (Alloway et al., 2004).

Pictures. The pictures task measures inhibition (Davidson et al., 2006; Burns et al., submitted). Children pressed response buttons on viewing picture stimuli on a screen. Pictures were of either a cartoon monkey, or a cartoon cat. Response buttons were labelled with the same cat and monkey pictures, with participants' task being to press the "cat-button" if they saw the cat and the "monkey-button" if they saw the monkey. Importantly, the cat and the monkey can appear in either spatially compatible or spatially incompatible locations. This task, then, measures a Simon type effect (Lu & Proctor, 1995; Simon, 1981). We have considered this to measure "simple inhibition", as it places only minimal demands on other executive functions. The task has been shown to not contain any element of Task switching (Davidson et al., 2006): spatially compatible and incompatible responses seem to be integrated into one rule. As response buttons are labelled this task is thought to contain relatively little in the way of working memory demands. Children completed 20 trials, equally split between spatially-compatible and spatially-incompatible trials.

A measure of Inhibition (simple) was calculated by subtracting the Processing Cost (Mean Response Time/ Proportion Correct) on Spatially Congruent trials from the Processing Cost on Spatially Incongruent trials.

Eyes Task. The Eyes task used (Burns et al., submitted) was an adaptation of the arrows task used by Davidson et al. (2006). On different trials, this task is thought to tax inhibitory demands and also demands on task switching. Children saw stimuli of schematic faces which either looked straight down, or at an angle of 45 degrees across the screen. Children were told to press the button the eyes were looking at. It is thought that in this task participants have to coordinate two arbitrary rules on viewing the schematic face sketches. Specifically when they see a head with eyes looking down they should press the button on the same side as the stimulus, yet when they see a head with eyes looking across they should press the button on the opposite side. It is possible to combine these rules into a single rule to “press the button the eyes are facing”, but interestingly, local switch costs on tasks such as these suggest that children do not do this (Burns et al., submitted). Children completed 20 trials of the eyes task evenly split between compatible and incompatible responses and between switch and non-switch trials. We have considered this task to measure “complex” inhibition as the task places demands on task switching and also greater demands on working memory (as response buttons are not labelled) than the pictures task.

Two measures were taken from this task. Firstly, a measure of Inhibition (complex) was calculated by subtracting the Processing Cost on Spatially Congruent trials from the Processing Cost on Spatially Incongruent trials. Secondly a measure of Task Switching was calculated by subtracting the Processing Cost on Non-Switch trials from the Processing Cost on Switch trials.

Memory span task. In the memory span task used (Burns et al., submitted; Davidson et al., 2006) children must remember an association between a series of arbitrary picture stimuli and one of two response buttons (which were not labelled). Pictures appeared in the centre of the screen and children had to press the appropriate button. Initially participants had to associate merely two stimuli (a football and an umbrella). Participants completed a practice set at this phase and 20 experimental trials. Following this a further two pictures were added (a telephone and a hammer) and children practiced specifically with these two new pictures before completing 20 experimental trials including all four pictures. Finally, two more pictures were added (a flower and some bananas), again followed by a practice set comprising only these stimuli. The last testing phase included 20 experimental trials using all six pictures. Children were not asked to respond quickly on this task, so the measure used is solely based on accuracy across the whole experiment.

5.2.1.3.2 *ToM measures*

Level-1 Visual Perspective-Taking. Children completed a Level-1 perspective-taking task. The task, first developed by Samson et al. (2010), and adapted for children by Surtees and Apperly (in press, Chapter 2), required children to take the perspective of a cartoon avatar on a series of trials. We also included an equal number of filler trials in which participants judged their own perspective. On each trial, participants viewed successive fixation stimuli (a smiling face (600ms) and a fixation cross (600ms)) followed by a 1800ms auditory stimulus (either “He sees N” or “You see N”, where N ranged from 1 to 3, so that the number of circles was within the range that could be enumerated quickly and accurately via subitization, Trick and Pylyshyn, 1994), and then the test picture depicting an avatar in a room with 1-3 dots

on the wall (see Figure 5.1). Participants pressed one of two colored keys to indicate whether or not the auditory stimulus correctly described the picture (on half of the trials, the auditory stimulus did match the picture, and on half it did not). Importantly, stimuli were either Consistent (so the Self and Other perspectives match) or Inconsistent (so that Other sees more than Self). Children completed 48 test trials: 24 where self and other perspectives were consistent (12 experimental, 12 filler) and 24 where self and other perspectives were inconsistent (12 experimental, 12 filler). Our dependent variable on this task was a measure of Egocentrism; calculated by subtracting Processing Cost on Other-Consistent trials from Processing Cost on Other-Inconsistent trials.

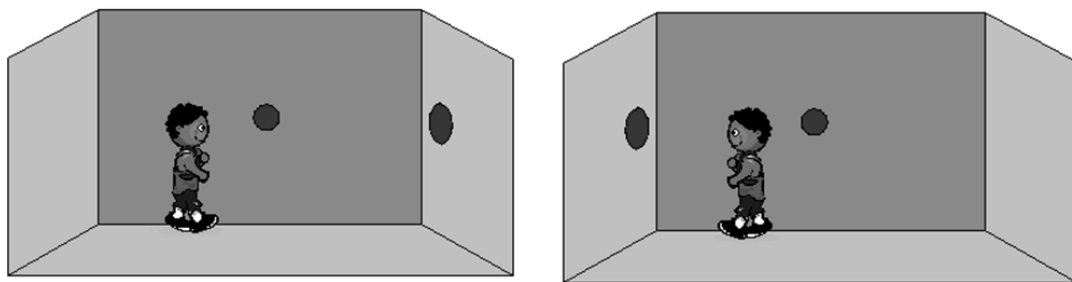


Figure 5.1. Example stimuli from the Visual Perspective-taking task. In a Consistent stimulus (left), participant and avatar share a perspective. In an Inconsistent stimulus (right), the participant views an additional circle.

Referential Communication. A computer-based task (adapted from real life versions, Epley, Morewedge & Keysar, 2004; Keysar et al., 2003) first used with adults (Apperly et al., 2010) and adapted for children by Dumontheil et al. (2010) required children to respond to the instructions of a director placed behind a grid. The director gave instructions for the participant to click on certain items within the grid.

Importantly, certain items were in common ground (they could be seen by both the director and the participant), whilst others were in the privileged ground of the participant (the director could not see them as on those items the grid had a solid background). Critically, on some trials objects in the grid had a scalar relationship (for example there was a large ball, a medium sized ball and a small ball). Keysar et al. (2003) found adult participants to show a cost when ignoring a seemingly relevant referent that could not be being referred to as it was in privileged ground. For example in Figure 5.2 if instructed to “click on the large jar” they may click on the jar containing mushrooms even though it is in privileged ground, whilst if we take the perspective of director, the jar with the cherries is the correct response. Children have been shown to be able to successfully complete this task, but errors do decrease with age (Dumontheil et al., 2010). The measure taken from this task was the number of egocentric errors (clicking on a response linked to one’s own viewpoint) made in comparison to equivalent errors on control trials. On this task, errors were used rather than processing costs as participants were not instructed to make responses quickly, and because previous studies using this paradigm had found effects to be manifest primarily in errors (e.g., Dumontheil et al., 2010).

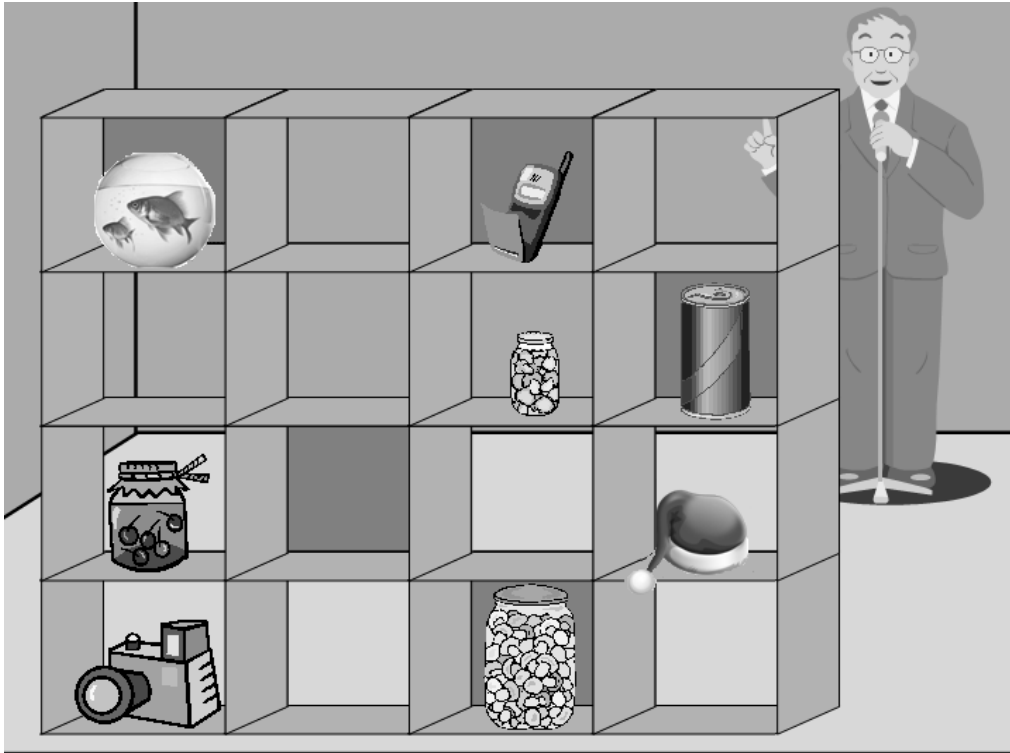


Figure 5.2. Example Stimulus from the referential communication task. Clicking on the largest jar would constitute an “egocentric error” as this is not in the view of the director.

Belief-Desire Reasoning. Participants completed a belief-desire reasoning task adapted from Apperly et al. (in press). In this task participants have to make judgements about where an avatar will look based on his beliefs and desires; he is opening boxes that may or may not contain food. Importantly his belief may be true or false (he does not always know where the food is) and his desire may be to approach the food (if he likes it) or avoid the food (if he hates it).

Children completed 16 trials with equal numbers of True and False belief trials paired with Approach and Avoidance desires. On each trial, first of all a voice stated the real location of the food; this was followed by the boy stating where he thought the food

was and whether he liked or hated it. Following this, children had to respond as to which box he would open.

Apperly et al. (in press), had found that children and adults make more errors on trials where the protagonist's belief was false and where their desire was to avoid the target. Thus we took two measures from this paradigm. A Belief-cost measure that was equal to the number of errors made on True Belief trials subtracted from the number of errors made on False Belief trials. A Desire-Cost measure was equal to the number of errors made on Approach-Desire trials subtracted from the number of errors on Avoidance-Desire trials. The advantage of using this composite variable, in comparison to the pure performance- as has been used in most developmental studies of ToM and executive functions, is that it controls for incidental performance in the task. The only difference between, for example, True-Belief Approach-Desire trials and False-Belief Approach-Desire trials is the need to interpret false beliefs. On this task, errors were used rather than processing costs. Error rates were high in this task, meaning for many participants some conditions yielded no correct responses from which to calculate response times.

5.2.2 Results

Results are divided into three sections. Firstly, we report descriptive data. Following this, we separately examine the profile of performance on the EF and ToM tasks, before finally analysing the relationship between individual differences across these different measures.

Table 5.1. Descriptive data of all measures and control variables.

	<i>Mean (Standard Deviation)</i>	
Theory of Mind		
Measures:		
	Proportion Correct	Response Time (ms)
Visual Perspective-taking		
Consistent	.92 (.21)	2297.69 (734.21)
Inconsistent	.87 (.20)	2289.35 (657.27)
Belief-Desire		
True - Approach	.85 (.26)	2730.25 (1011.74)
True- Avoid	.57 (.35)	2956.85 (1143.40)
False - Approach	.55 (.36)	2880.28 (1195.71)
False - Avoid	.49 (.35)	2923.17 (1091.44)
Referential		
Communication	Errors- Proportion (S.D)	
Experimental	.49 (.19)	
Control	0	
Other	.13 (.11)	
Executive		
Measures:	Proportion Correct	Response Time (ms)

Pictures		
Congruent	.96 (.071)	855.69 (191.84)
Incongruent	.81 (.11)	948.51 (220.00)
Eyes		
Congruent	.93 (.11)	1057.91 (277.50)
Incongruent	.81 (.19)	1089.94 (231.65)
Switch	.83 (.16)	1139.16 (285.39)
Non-Switch	.90 (.12)	1024.58 (239.68)
Memory Span	.77 (.13)	
	Score	
Counting Recall	14.77 (4.38)	

5.2.2.1 Executive Function Measures

Data from executive function measures are a subset of data also presented in another study (Burns et al., submitted).

Pictures Task. Consistent with the reported literature, participants performed more accurately ($t(56) = 10.26, p < .001$) and more quickly ($t(56) = 5.74, p < .001$) on Congruent as compared to Incongruent trials.

Eyes Task. As with the pictures task, Congruency had an effect on both the speed ($t(56) = 2.09, p = .042$, Congruent < Incongruent) and the Accuracy ($t(56) = 4.99, p < .001$, Incongruent < Congruent) of responses. Additionally an effect of switching was found: Switch trials were performed more slowly ($t(56) = 5.05, p < .001$) and with less accuracy ($t(56) = 4.74, p < .001$) than Non-Switch trials.

5.2.2.2 ToM measures

Level-1 Visual Perspective-Taking. A paired-samples t-test revealed an effect of Consistency on Accuracy ($t(56) = 2.36, p = .022$; Consistent > Inconsistent). This demonstrates the predicted effect of egocentrism. An equivalent t-test on Response Times revealed no significant effect of Consistency on Response Times ($t(56) = .19, p = .85$; Inconsistent > Consistent). Response Times did not demonstrate the effect of Consistency, as had been shown in a similar age group by Surtees and Apperly (in press; Chapter 2), but it remains likely that these data did reflect valid individual differences, and so they were combined with error data to give a single index of processing cost.

Referential Communication. The critical error type on experimental trials of the referential communication task was for participants to select a referent that the director could not see, but which fit with his instruction (e.g., In Figure 5.2 the error would be to select the largest of the three jars in response to the instruction to “Click on the large jar...”). Control trials supplied the baseline for comparison with this failure of ToM-use, which was the rate at which participants selected an item that the director could not see from the same spatial position on the grid, when this item did not fit with his instruction. These two error types formed the basis for our analysis. Participants could also make errors by selecting items that did not fit with the director’s instructions from other spatial positions on the grid. This error rate is reported in Table 5.1 but these errors cannot be interpreted as a failure of perspective-taking, and following Apperly et al., (2010) they were not analysed further.

In fact participants never made errors on the baseline control trials. This meant that parametric tests could not be used to compare the baseline with the error rate on experimental trials. A Wilcoxon test was carried out to investigate performance, and revealed that significantly more errors were made on experimental trials than control errors ($z = 6.18, p < .001$).

Following Keysar et al. (2003), Apperly et al. (2010), Dumontheil et al. (2010) we found evidence of participants making errors of ToM use. Participants in the current study failed to take into account the perspective of the director on almost half of all trials where this could be shown to make a difference; participants never made equivalent errors on control trials, therefore these errors appear due to the perspective-taking demands of the task, rather than more general performance demands.

Belief Desire Reasoning. A 2x2 ANOVA on proportion of correct responses with Belief (True, False) and Desire (Approach, Avoid) as independent within-subjects factors revealed a main effect of Belief ($F(1, 56) = 25.74, p < .001, \eta^2 = .32$; True > False), a main effect of Desire ($F(1, 56) = 9.75, p = .003, \eta^2 = .15$; Approach > Avoid) and an interaction between Belief and Desire ($F(1, 56) = 13.34, p = .001, \eta^2 = .19$). Paired samples t-tests revealed that the effect of Desire was significant for True beliefs ($t(56) = 4.92, p < .001$; Approach > Avoid), but not for False Beliefs ($t(56) = .910, p = .37$).

5.2.2.3 Individual Differences

We first examined the correlations within the sets of ToM and Executive Function tasks.

5.2.2.3.1 *Theory of Mind*

Table 5.2. Correlations between Theory of Mind measures (Partial correlations controlling for Age and BPVS).

	Perspective- taking Egocentrism	Referential Communication Errors	Belief Cost	Desire Cost
Perspective- taking Egocentrism	1.00 (1.00)	-.188(-.116)	-.121(-.129)	-.123 (-.087)
Referential Communication Errors		1.00 (1.00)	-.044 (-.059)	.017 (.019)
Belief Reasoning			1.00 (1.00)	.125 (.183)
Desire Reasoning				1.00 (1.00)

There were no significant correlations between any of our measures obtained from the Theory of Mind paradigms.

5.2.2.3.2 *Executive Functions*

Table 5.3. Correlations between Executive Functions (Partial correlations controlling for Age and BPVS).

	Inhibition (Complex)	Inhibition (Simple)	Task Switching	Working Memory	Memory Span
Inhibition (Complex)	1.00 (1.00)	.111 (.129)	-.101 (-.203)	-.071 (-.087)	-.235 ⁺ (-.235 ⁺)
Inhibition (Simple)		1.00 (1.00)	.116 (.156)	-.131 (-.240 ⁺)	-.275* (-.303*)
Task Switching			1.00 (1.00)	-.120 (-.038)	-.087 (-.132)
Working Memory				1.00 (1.00)	.215 (.236 ⁺)
Memory Span					1.00 (1.00)

⁺ $p < .1$, ^{*} $p < .05$

When Age and BPVS were partialled out, the only significant correlation was between our measure of Memory span and Inhibition (low memory demand). There were also trends for a relationship between Memory Span and Working Memory, Memory Span and Inhibition (high memory demand) and between Inhibition (low memory demand) and Working Memory.

5.2.2.3.3 *Theory of Mind and Executive Functions*

Table 5.4. Correlations between Executive Function and Theory of Mind (Partial correlations controlling for Age and BPVS score).

	Perspective- taking Egocentrism	Referential Communication Errors	Belief Cost	Desire Cost
Inhibition (Complex)	.383** (.365**)	.064(.093)	.153 (.112)	.091 (.140)
Inhibition (Simple)	-.146 (-.133)	.082 (.040)	.205 (.306*)	-.144 (-.182)
Task Switching	.381** (.295*)	-.163 (-.134)	.044 (.109)	-.243 (-.137)
Working Memory	-.151(-.04)	.191 (.139)	.122 (-.098)	-.145 (-.256)
Memory Span	-.115. (.121)	.124 (.106)	-.225 (-.357*)	.075 (.072)

* $p < .05$, ** $p < .01$

Exploratory correlations between our measures of Theory of Mind and Executive Function were carried out. There was a strong positive correlation between Egocentrism on the perspective-taking task and Inhibition (complex). Participants who suffered most egocentric interference were also those who had most trouble ignoring a pre-potent response, even when Age and Vocabulary ability were controlled for. There was also a strong positive correlation between Egocentrism on the perspective-taking task and Task Switching. Participants who suffered most egocentric interference were also those who had most trouble switching between

rules, even when Age and Vocabulary ability were controlled for. When effects of Age and Verbal ability were partialled out, Belief Cost correlated negatively with Memory Span and positively with Inhibition (simple): children with a greater memory span and a smaller inhibitory cost suffered a smaller cost of reasoning about false beliefs. Our measures of Desire Cost and Referential Egocentrism did not correlate with individual differences in executive functions.

5.2.2.3.4 *Regression Analyses*

In order to identify the specific contributions made by individual executive components when other components and our control variables were accounted for, a series of hierarchical linear multiple regressions were carried out. As our ToM variables were unrelated to one another, we did not combine them in any way.

5.2.2.3.4.1 *Visual Perspective-taking.* Age and Vocabulary ability were entered in the first block. Neither Age ($\beta = -.12, t = -.87, p = .39$) nor Vocabulary ($\beta = -.26, t = -1.87, p = .067$) was a significant predictor of egocentrism. From previous findings in the area, and consistent with our partial correlations, we entered Inhibition (complex) in the second block of our regression, finding it to be a significant predictor ($\beta = .36, t = 2.63, p = .012$). Following this our other executive measures were entered: Task switching, Inhibition (simple), Memory span, Working Memory. Only Task Switching made a significant further contribution to the model. The final regression model significantly predicted Egocentric Interference (adjusted $R^2 = .28, p < .05$). Inhibition (complex) ($\beta = .45, t = 3.38, p = .002$) and Task Switching ($\beta = .42, t = 2.96, p = .005$) significantly predicted unique variance in this model. Table 5.5 illustrates the final model.

In a second regression, we reversed the order of entry; this time other measures of executive function were entered before Inhibition (complex), and at this stage, only Task Switching ($\beta = .687, t = 2.106, p = .041$) significantly predicted Egocentrism. When Inhibition (complex) was subsequently added, it made a significant further contribution to the model. The final regression model significantly predicted Egocentric interference (adjusted $R^2 = .28, p < .05$), with both Task Switching ($\beta = .42, t = 2.96, p = .005$) and Inhibition (complex) ($\beta = .45, t = 3.38, p = .002$) being significant predictors of Egocentrism ($\beta = .47, t = 3.58, p = .001$). Taken together with the results from the first regression analysis, this pattern suggests that both Inhibition (complex) and Task Switching make independent contributions to explaining variance in Egocentrism on the perspective-taking task.

5.2.2.3.3.2 *Belief Cost.* As with visual perspective-taking, we completed two hierarchical multiple regressions to find predictors of belief cost. When entering our memory measures initially, memory span approached significance ($\beta = -.24, t = -.17, p = .10$), but none of the variables remained significant predictors in the final model (see Table 5.5). When entering our inhibitory measures initially, the strongest predictor was Inhibition (Simple), but this did not reach significance ($\beta = .21, t = 1.48, p = .15$).

Table 5.5. Final Regression coefficients predicting Egocentrism in Visual Perspective-taking and Belief Cost.

<i>Variable</i>	<i>B</i>	<i>T</i>	<i>P</i>
a) Egocentrism in Visual Perspective-taking			
Age	.045	.347	.951.
BPVS	.029	.188	.731
Inhibition (Complex)	.451	3.375	.002**
Inhibition (Simple)	-.263	-1.977	.055
Switching	.421	2.962	.005**
Working Memory	-.046	-.326	.746
Memory Span	-.058	-.443	.660

b) Belief Cost			
Age	-.187	-1.269	.211
BPVS	-.082	-.489	.627
Inhibition (Complex)	.052	.352	.727
Inhibition (Simple)	.222	1.454	.153
Switching	-.101	-.621	.538
Working Memory	.186	1.159	.253
Memory Span	-.189	-1.258	.215

 $p < .01$

In sum, regression analyses confirmed Inhibition (complex) and Task Switching to be strong predictors of Egocentrism in visual perspective-taking, even when a whole range of other factors were entered. For Belief Cost, the pattern was less clear. Inhibition (simple) and Memory span both came close to predicting ability to reason about false belief, but neither variable was significant in the analyses conducted.

5.3 *Discussion*

There is good evidence that individual differences in ToM and Executive Functions are linked in pre-school children (Carlson & Moses, 2001). Specifically, Inhibitory ability predicts ToM performance, over and above working memory or planning ability (Carlson et al., 2004); this is particularly pronounced when the measures of inhibition themselves tax heavily on memory (Moses, 2001). The current paper found meaningful individual differences in both Executive Function and ToM in older children and investigated links between these differences.

Children completed three tasks measuring discrete, yet seemingly related, forms of ToM (Level-1 Perspective-taking, Referential Communication and Belief-Desire Reasoning) and four tasks designed to measure the executive functions: specifically measuring Inhibition (both simple and complex), task switching, working memory and memory span. Each of our ToM measures provided a measure of egocentrism. Our belief-desire reasoning task also allowed for measurement of the related effect experienced when reasoning about avoidance desires rather than approach desires.

Partial correlations, controlling for Age and Verbal ability, demonstrated a relationship between egocentrism in our visual perspective-taking task and our measure of complex inhibition and our measure of task switching. Follow up hierarchical regressions showed both of these measures to be strong predictors of levels of egocentrism in visual perspective-taking even when the other measure was entered first into the model, suggesting that both measures made unique contributions to explaining performance on the perspective-taking task. For the belief-desire task, although exploratory correlations suggested a relationship between the cost of

reasoning about false beliefs and both memory span and simple inhibition, a linear regression found neither of these variables to be significant predictors of belief reasoning in the final regressions models. It cannot be said, therefore, that either reliably predicts variance in error rates when reasoning about false beliefs in this age group. Error rates when reasoning about avoidance desires and avoiding self perspective in a referential communication task did not show any link to executive abilities.

5.3.1 Convergence amongst ToM Measures

Traditional studies investigating the development of ToM have shown a strong degree of convergence between different measures. When researchers have used batteries of ToM measures to gain an overall measure of children's ToM, a good degree of covariance was shared between ToM measures (Carlson & Moses, 2001; Hughes and Ensor, 2007). In the majority of cases, however, these measures, whilst using different methods, have assessed reasoning about very similar concepts. For example, studies commonly use both unexpected contents tasks (Hogrefe, Wimmer & Perner, 1986) and a change of location tasks (Wimmer and Perner, 1983), which have very different methods, but are both thought to assess reasoning about false beliefs. The present study both tests older children than used in these studies, and on a much broader range of abilities thought to be involved in ToM. Interestingly, whilst each of our tasks generated effects that could be viewed as indexing egocentrism, we found that these independent measures were not related.

That Belief reasoning does not correlate with these other forms of perspective-taking, is perhaps not that surprising; explicit tests of these abilities suggests that explicit

belief reasoning does not develop at the same time as the other abilities we tested. Pre-schoolers show the ability to process the Level-1 perspectives of others (Moll & Tomasello, 2006) and respond in a way that is referentially sensitive (O'Neill & Topolovec, 2001), but these children do not give correct responses in reasoning that requires thinking about the false beliefs of others until around the age of four (Wellman et al., 2001). One possibility, then, is that this more complex belief and desire reasoning requires different resources from simple Level-1 perspective taking, thus we should not expect that children who are good at one ability to be necessarily good at the other. That Level-1 perspective egocentrism and referential egocentrism do not correlate is perhaps more surprising, given that both required the same underlying concept of Level-1 perspective. However, as suggested above, as well as by Samson and Apperly (2010), variability in performance on referential communication tasks may be due to factors other than the need for perspective-taking *per se*, such as variation in the ability to assimilate a large array of objects, which may not be tapped by any of the measures of executive function used in the current study (or by our Level-1 perspective-taking task).

5.3.2 *Inhibition and the link to perspective-taking*

Many studies have shown a strong link between ToM and inhibition; in particular, those children who are the first to pass False Belief tasks are those children who perform better on tasks testing their inhibition (Carlson & Moses, 2001; Hughes & Ensor, 2007; Moses, 2001). Inhibitory abilities are also found to predict False Belief performance even when it is tested much earlier (Carlson et al., 2005). In particular, conflict inhibition seems to be related to ToM (Moses, 2001; Nilsen & Graham, 2009). Also, patients with brain injury resulting in inhibitory problems have also been

shown to fail false belief tasks when their own perspective is salient (Samson et al., 2005).

In the current study, we found unique new evidence regarding the link between inhibition and perspective-taking. Firstly, this is the first study to relate executive functions to a Level-1 Perspective-taking task (Moll & Tomasello, 2006). Level-1 perspective-taking has been demonstrated as a particularly early developing ability. Unlike many other ToM tasks, Level-1 perspective-taking tasks have been passed by children as young as 2-years of age, even when explicit responses are required. Secondly, we tested older children with considerably more inhibitory abilities than those previously tested. Finally by using a task involving perspective-congruency *as well as* perspective-incongruency we were able to test the central idea of egocentrism. We specifically measured our participants' ability to ignore their own perspective- this is normally conflated with ToM in general. Whilst one component of most ToM tasks is to avoid one's own perspective, ToM has many other components. Subtracting performance on trials in which perspectives are congruent from those in which they are incongruent leaves a measure that isolates the tendency for egocentrism more precisely than existing measures. Our inhibition task with higher memory demands correlated with egocentric interference suffered by children on a Level-1 perspective-taking task. Previous studies have suggested that the relationship between conflict inhibition and ToM is due to perspective-taking tasks requiring participants to inhibit a salient view of the world; either a view that is specifically attributed to self, or one that is merely representative of a "good" view, (Light & Nix, 1983). Inhibiting such a salient view is thought necessary to take the viewpoint of another (Rakoczy, 2010). Our results show that inhibition links specifically to a

measure of egocentrism, not just ToM in general. This suggests that the relationship between inhibition and ToM is truly linked to resolving perspective incongruency, rather than creating a representation of a non-self perspective in general. In the current study, it was not the case that all measures of inhibition correlated with egocentrism, in fact, we found that egocentrism only correlated with our measure of inhibition on the eyes task. We suggest the key difference between this task and the pictures task to be in the level of other executive demands placed by each: in the eyes task children have to remember two abstract rules relating to the stimuli, and switch between them, in the pictures task they only need to remember one, and perhaps just as importantly, response buttons are labelled, so matching is all that is required. We suggest that this fits well with previous findings from younger children. Conflict inhibition has been found to relate much more strongly to ToM than delay inhibition and it has been suggested that what facilitates this relationship is memory (Moses, 2001).

5.3.3 Relationship between task switching and Visual Perspective-taking

That children's ability to switch between abstract rules predicts their ability to ignore their own perspective suggests that one of the problems involved in avoiding egocentrism is in switching away from one's own perspective. It is important to remember that in our visual perspective-taking task, participants are informed prior to each trial whose perspective they are taking. The predictive relationship suggests two possible explanations. Firstly, the relationship may be afforded by participants first taking their own perspective and then adjusting this to the perspective of the avatar. Such a hypothesis, which, in the past, has been suggested as a way in which perspective-taking might be achieved, is known as egocentric anchoring and adjustment (Epley et al., 2004). Alternatively, the relationship may be afforded by a

relatively incidental element of the task: although informed prior to the trial that they will be not taking their own perspective, previous “self” trials may still have a residual effect on processing. Whilst in some ways this alternative is less interesting, it is certainly the case that in every day perspective-taking we often have to rapidly switch between our own perspective and that of another, suggesting that these incidental demands may actually mirror everyday demands of perspective-taking. Determining which of these hypotheses is correct would be relatively simple in a further study in which participants completed self and other perspective-taking in separate blocks. Egocentric anchoring and adjustment would predict an equivalent relationship between egocentrism and task switching to the one observed here. In contrast, if the relationship is predicated on the demands of judging both Self and Other perspectives within a single block of trials, the effect should not remain when Self and Other trials occur in separate blocks.

5.3.4 Predicting Reasoning about False Beliefs

Our measure of belief-desire reasoning with executive functions showed tentative links to memory span and inhibition with low memory demands. It has commonly been observed in studies of younger children that ToM, and in particular belief-reasoning, should correlate with measures of both memory and inhibition (Carlson & Moses, 2001; Carlson et al., 2002; Carlson et al., 2004; Hughes 1998a, 1998b; Hughes & Ensor, 2007; Moses, 2001; Perner & Lang, 1999). However, in the current study, neither of these variables remained significant predictors in final regression equations, so interpretation of the partial correlations must be tentative. The need for caution is compounded by children’s relatively poor overall performance on this task. Nonetheless, given the specific nature of the task presented, one suggestion would be

that memory span correlated with performance as this allows for holding in mind both the belief of the avatar and reality. Inhibition on the other hand, may be crucial in avoiding a reality bias at response. It would be important for future work to test these hypotheses in a sample of older children who could produce reliable response time data as well as the error rates analysed in the current study.

5.3.5 Why is Referential Communication not linked to any executive abilities?

In our task we found referential egocentrism to show no relation to any executive ability. This was surprising as Nilsen and Graham (2009) had shown links to both working memory and inhibition in a conceptually similar task at a similar age group. We suggest that we may not have found these relationships due to our task using a much larger array (with more possible referents). Whilst performance of children in our task was similar to that shown in a similar age group previously (Dumontheil et al., 2009), it was much poorer than that shown by Nilsen and Graham (2009). We suggest, then, that performance in our task may have made demands on very general non-executive processing abilities rather than specific executive functions. Such general processing demands, and in particular the ability to interpret a large array of objects, are suggested by Samson and Apperly (2010) to potentially explain why tests of referential communication are effortful, in spite of seeming to only require Level-1 perspective-taking.

5.3.6 Performance and Individual Differences

In the current study, we showed that individual differences in different measures of ToM did not correlate with one another. When relating ToM to the Executive Functions, there were also several cases in which relationships found in younger

children in previous studies were not replicated in their older counterparts in the current study. It is certainly possible that our current study is limited by the relatively poor performance that was observed on some of our ToM tasks. Given that ToM abilities are likely to continue to improve through mid to late childhood it would be valuable for a future study to employ similar tasks with a wider range of ages and a wider range of successful performance. Nonetheless a further point on the nature of individual differences is also worthy of consideration. Individual differences inform us about the limiting factors on an aspect of performance on a given task at a given age. To make this clear: just because individual differences in our measures of inhibition did not correlate with individual differences in our measure of belief reasoning, this does *not* mean that inhibition is not required when ignoring one's own conflicting belief, even in the age group of children studied here. Rather what it means is that inhibitory control, as measured by our tasks, does not dictate whether a child at this age will be particularly good at the task. Of course, the same principle applies to findings in early childhood, in that the relative emphasis on inhibition in comparison with working memory or switching (Carlson & Moses, 2001) means that inhibition *is* a critical limiting factor in this age group; it does not mean that memory or switching are not involved in performing ToM tasks in these younger children. With this in mind, the lack of common variance between ToM measures in our sample of 6-7 year-olds suggests that even though some aspects of ToM may be domain specific, fluency of performance in this age group may depend on a variety of non-overlapping executive factors. Thus, although it seems highly likely that all aspects of ToM have common conceptual foundations, this really does not necessitate that individual differences in ToM performance at a given age will be based on an

individual's conceptual capacity. Different specific *or* general abilities may provide limits to performance on seemingly similar tasks.

5.3.7 *Conclusions*

Studying Executive Functions and ToM has been a fruitful area of research for the past 15 years, mostly focussing on the performance of pre-school children. These studies have been informative of the cognitive correlates of young children's emerging explicit understanding of the minds of others. What is less clear is what supports changes in performance once this conceptual apparatus is in place. New paradigms have demonstrated measurable individual differences in ToM well beyond the age of four years (Apperly et al., in press; Dumontheil et al., 2009; Surtees & Apperly, in press, Chapter 2). The current study found both inhibition and task switching to relate to children's ability to ignore their own perspective in a Level-1 perspective-taking task. No other executive measures significantly predicted ToM performance. Further information on how these two complex cognitive domains interact in older children and adults may provide the key to understanding what dictates ToM performance well beyond the time at which ToM concepts emerge.

5.4 Summary and links to Chapter 6

Experiments 1-4 have investigated different aspects of perspective-taking. I have examined how cognitive processes for perspective-taking vary with age (Chapters 2 and 3), how different kinds of information are represented as perspectives (Chapters 3 and 4) and what executive abilities predict success at perspective-taking tasks in children (Chapter 5). What the preceding five chapters have not investigated is what generates a perspective. When we consider what someone else sees, it is clear that this requires a relationship between the individual and the object predicated on our belief that the individual has eyes, and potentially a mind, able to “see” things at all. Research in perspective-taking has not only focussed on psychological perspective-taking, but has also considered spatial perspectives: the relationship between an individual and an object in space; for example a ball being to the right of a man. Such perspectives are remarkably similar in character to judgements using spatial frames of reference, which involve using either our own position or the position of an object to define where two objects are in relation to one another. In Chapter 6 I investigate spatial frames of reference in situations where objects are related to people and to other objects.

CHAPTER 6

Losing yourself in space: Children and adults' use of multiple reference frames

This chapter has been submitted as the article: Surtees, A. D. R., Noordzij, M. L. & Apperly, I. A. (submitted): Losing yourself in space: Children and adults' use of multiple reference frames

6.0 Abstract

Two experiments tested 6-11 year old children's and adults' use of different frames of reference when making judgements about social and non-social scenes. In Experiment 5A, both children and adults ($N = 144$) showed spontaneous sensitivity to the intrinsic and the relative frame of reference when making decisions about the appropriateness of written statements. This was the case when judging both social and non-social scenes. All groups older than the age of 7 showed a stronger effect of the intrinsic frame of reference for social stimuli. This is the first evidence of sensitivity to more than one frame of reference in single judgements made by children. In Experiment 5B, we again tested children aged 6-11 and adults ($N = 185$). Manipulating task demands caused participants to lose sensitivity to the, self-based, relative frame of reference. This effect of "losing yourself in space" was caused by presenting participants repeatedly with stimuli using the same referent. Interestingly, children only showed this effect when the stimuli were social, suggesting that spontaneous use of intrinsic frames of spatial reference may develop out of sensitivity to the perspectives of agents.

6.1 Introduction

Many years of research into social perspective-taking, spatial perspective-taking and spatial frames of reference have provided evidence of the cognitive processing of the relationships between entities in our environment. Perspective-taking judgements and frame of reference judgements seem to require similar resources, such as inhibition, which is used in selecting between spatial frames of reference (Carlson-Radvansky & Jiang, 1999), used in perspective-taking/selection (Qureshi, Apperly & Samson, 2010) and also in the development of Theory of Mind (Carlson & Moses, 2001; Hughes,

1998; Hughes & Ensor, 2007). In spite of such similarities, there has been little research that actually compares perspective-taking and frame of reference use and how these abilities might interact. Also surprising has been the difference in attention paid to each literature by developmental psychologists: social perspective-taking research has been dominated by developmental findings on how children progress towards maturity, whilst many spatial tasks have never been attempted with young children. The current studies bring these rather separate strands of literature together to examine processing of spatial frames of reference for social agents and non-social objects in children and in adults.

6.1.1 Frames of Reference

Knowing and being able to communicate the relative locations of objects has clear adaptive advantages, for example when caching food, or avoiding competitors (Newcombe & Hunterlocher, 1992). In order for us to understand a speaker's intention when referring to the relative positions of people and objects, one must take into account a given frame of reference (Levinson, 1996). That is to say, to understand the meaning of a linguistic utterance in light of our perceptual cues, we must map them onto an internal representation of space (Carlson-Radvansky & Irwin, 1993). It is considered that there are 3 distinct ways in which we can define such spatial relations (Levinson, 1996; 2003). The absolute frame of reference denotes references related to some (usually invariable) element of the environment (for instance North-South relations). The relative frame of reference locates the position of objects relative to the viewer. The intrinsic frame of reference locates the position of objects with reference to the plane of one of the objects in the scene (the referent object). These frames of reference may be either consistent or inconsistent with each

other. We illustrate this point with the relative and intrinsic frames of reference, because of their importance to the current work. In Figure 6.1 (Panel B), if we consider only the intrinsic frame of reference, the ball is in front of the boy, in virtue of being on a line extended from *his* front. If we consider only the relative frame of reference, the ball is now behind the boy, this time in virtue of being further from *us* than the boy is. Alternatively, they can be consistent with one another, as in Figure 6.1 (panel D). This time it should be clear that using either reference frame, the ball is *in front* of the boy

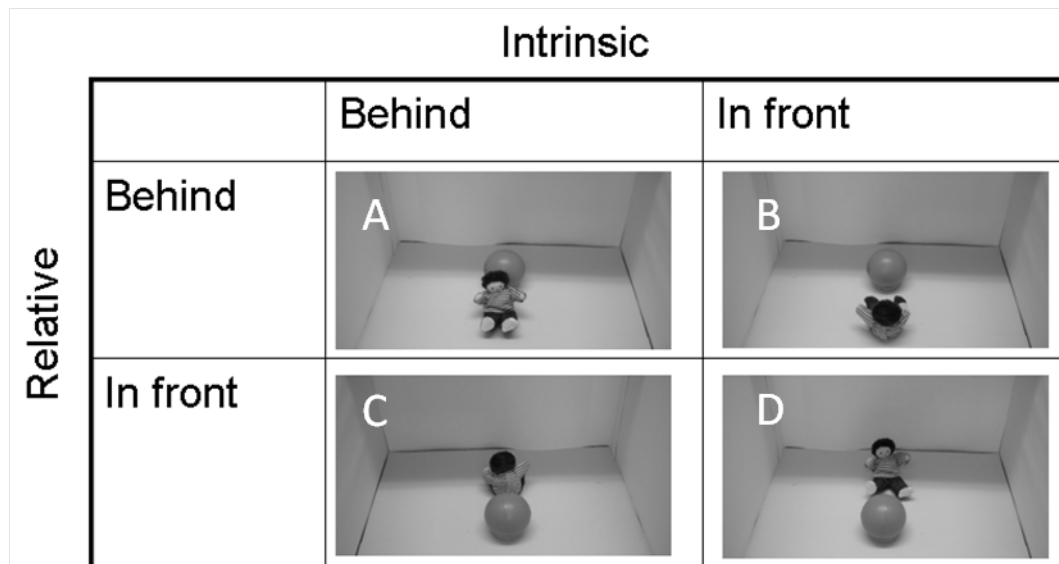


Figure 6.1. Stimuli for Social condition, illustrating frame of reference manipulation (columns indicate relation of ball to boy with regard to the intrinsic frame of reference and rows with regard to the relative frame of reference). Varying the rotation of the referent object manipulates the intrinsic frame of reference without altering the relative frame of reference. Varying the order of the referent and the target objects on the z-axis manipulates the relative frame of reference without altering the intrinsic frame of reference.

Adults spontaneously activate multiple frames of reference when making judgements about the positions of objects in relation to each other (Carlson & Van Deman, 2008; Carlson-Radvansky & Irwin, 1993; Carlson-Radvansky & Jiang, 1998). Carlson-Radvansky and Irwin (1993) showed that when asked to rate the appropriateness of written statements adult participants showed sensitivity to both the intrinsic and the relative frames of reference. In their task, participants rated the acceptability of spatial relations between objects using the referent “above” and showed a strong preference for the relative reference frame (which also coincided with the absolute reference frame in this task). Nonetheless, when effects of the relative frame of reference were controlled for, adults also showed a preference for statements appropriate for the intrinsic frame of reference over those that were inappropriate on this dimension. This implies not only that both frames of reference provide acceptable criteria on which simple spatial relations such as ‘above’ can be judged, but also that adults are spontaneously sensitive to both of these frames of reference in the very same stimuli. It remains unknown whether children spontaneously activate multiple reference frames in similar circumstances.

6.1.2 Children’s use of frames of reference

Work on children’s frame of reference use and understanding has followed a different path from that with adults, focussing either on children’s use of landmarks (Huttenlocher & Presson, 1984; Rieser, 1979), the use of spatial terms such as front and back (Bialystok & Codd, 1987; Cox, 1981; Harris & Strommen, 1973) or their ability to use information where only one frame of reference is relevant (Nardini, Burgess, Breckonridge & Atkinson, 2006). To our knowledge, there are no published data on whether children are spontaneously sensitive to multiple frames of reference

when they make single judgements. This is an important gap in the literature, for two reasons. Firstly, in order to interpret the spatial language of mature users, children must learn to be able to flexibly consider more than one alternative spatial frame of reference. Secondly, flexibly moving between a relative and an intrinsic frame is analogous to flexibly moving between one's own and another's perspective. This flexible perspective taking is important in keeping an up to date view in order to communicate relevant information to another (Sperber & Wilson, 1986).

Piaget and Inhelder (1956) portrayed children's spatial understanding as being egocentric, with children being unable to generate projective spatial relations. In other words, they felt that children were unable to understand relations that were independent of their own position in the world. More recently, however, there has been strong evidence that this is not the case, with infants showing sensitivity to the intrinsic as well as relative (egocentric) frame of reference (Bremner, Bryant & Mareschal, 2006; Bremner, Bryant, Mareschal & Volein, 2007) and young children also using information from different reference frames where relevant (Nardini et al., 2006). Investigation of children's drawing also works against the idea of self perspective holding primacy, with children beginning by using object-centred information, before transferring to using more viewer-centred cues (Taguchi, 2004). Whilst infants seem to be sensitive to multiple frames of reference, it seems likely that explicit use and cultural specificity are conveyed through language (Levinson, 1996). Relevant to this, it is thought that Western children are taught intrinsic frames of reference first, but do not master this until the age of four (Johnston & Slobin, 1979). Such findings suggest either that children are more flexible than traditionally thought or that they are dominated by a "good view" as opposed to their "own view" (Light &

Nix, 1981). Light and Nix's distinction concerns whether children have a specific problem with ignoring their own spatial location (suggesting that children's default should always be the relative frame of reference), or a more general problem with flexibly selecting perspectives other than the one "good view" that strikes them as most immediately salient (suggesting that children's default perspective should vary as a function of the task). Observing the development of use of different reference frames may inform us as to which of these is more likely.

Although no study has addressed whether children spontaneously use more than one frame of reference when interpreting linguistic cues, a number of studies have investigated children's preferences in single judgements. Harris and Strommen (1973) found children to ignore their own position in the world when making spatial arrangements. When asked to place an object "in front" of another object, children consistently used the intrinsic frame of reference to guide their judgements. Harris and Strommen (1973) present this as evidence that children initially fixate on rigid single uses of such terms. This idea of a conceptual "good view" was challenged by results from a similar study (Cox, 1981). Cox (1981) found children consistently used the intrinsic frame of reference for judgements where possible and used the relative frame of reference if it was not. Bialystok and Codd (1987) tested participants from 3-years old to adulthood in a task that involved placing an item in front or on top of objects. Bialystok and Codd (1987) found a bias at all ages for using the object's intrinsic frame of reference when asked to place objects "in front" and using the relative frame of reference when asked to place objects "on top". There were no clear signs of developmental change in the bias.

Importantly, these findings suggest that children are not rigidly stuck to one reference frame for consistent use of a term such as “in front”. At least when considered as a group, children from the age of 4 years show the ability to use both the relative and intrinsic frames of reference. Also, it is clear that the intrinsic frame of reference takes precedence when children are forced to make a choice as to where is “in front”. What existing evidence does not show is whether children, like adults, consider more than one reference frame when making judgements.

In the present study we adapted a method used with adults by Carlson-Radvansky and Irwin (1993) in order to ask both children and adults to make judgements of the acceptability of statements at describing pictures. This provides the first test of whether children spontaneously consider multiple frames of reference when judging a single set of stimuli.

6.1.3 Social Aspects of Frame of Reference Judgements

One reason to be interested in spatial judgements in general and in the intrinsic frame of reference in particular is the potential social significance of these judgements. The literature on frames of reference has tended to focus purely on arbitrary objects, without considering that for some objects (such as agents) the intrinsic frame of reference may be far more salient than for other objects (such as non-agents), because it coincides with an agent’s perspective. In particular, there has been no concerted effort to look at the specific case of people as fronted objects, by asking whether it is the same to say that “it is in front of him”, as it is to say “it is in front of that”? Interestingly, a rather separate body of research on spatial perspective-taking (SPT) has suggested that when we have to explicitly judge where an object is in relation to

another person, we do so by actively projecting ourselves (and rotating) into their position (Kessler & Thomson, 2010; Kozhevnikov, Motes, Rasch & Blajenkova, 2006; Michelon & Zacks, 2006). Similarly, research on social perspective-taking has tended to suggest this to be a cognitively effortful process. Children and adults show egocentric biases in their judgments about the perspectives and mental states of others (Birch & Bloom, 2004; Epley, Morewedge & Keysar, 2004; Nickerson, 1999), and it has been suggested that this is because they originally take their own perspective and then effortfully change to a different point of view, a process termed “egocentric anchoring and adjustment” (Epley & Gilovich, 2001; Epley, Morewedge & Keysar, 2004). Such evidence suggests that explicit spatial or social perspective-taking is a relatively demanding process, raising questions about whether it is plausible that this is what listeners are doing online when they take account of the frames of reference of objects.

However, not all perspective-taking has been found to be so effortful. Tversky and Hard (2009) demonstrated that many participants would spontaneously represent a scene from the spatial perspective of another person when merely asked to describe a scene. For example, when participants viewed a scene with a man facing them with a book on the right hand side of the scene, they regularly described the position of a book as being “to his left” when instructed to merely describe the position of the book. Such behaviour was enhanced by the social engagement of the person in the scene with the object, suggesting that such preference for the (social) intrinsic frame of reference of a person serves a social function. In another demonstration of adults’ sensitivity to the perspectives of others Samson, Apperly, Braithwaite, Andrews and Bodley-Scott (2010) found evidence that adults automatically took the visual

perspectives of others as well as their own. Such evidence suggests that adults may sometimes process the spatial and visual perspective of agents even when they are not asked to do so, and in the case of Samson et al. (2010), that they do so quickly enough that it disrupts judgements about their own perspective.

Given this rather mixed evidence on the cognitive demands of perspective-taking in adults, we were interested to investigate whether the nature of a referent object – whether it was an agent or a fronted object – would alter participants' spontaneous processing of spatial frames of reference.

6.1.4 The Current Studies

We tested children and adults on a linguistic frame of reference task in which they had to interpret the appropriateness of statements describing the position of two objects in relation to one another. We used front-back relations to allow us to test relatively young children and to provide the strongest association between the perspective of the social cues and the intrinsic frame of reference. The study extends current knowledge in being the first to systematically examine whether people are in any way special as fronted objects when participants interpret verbal descriptions of a scene. As such it provides a direct test of the influence of perspectives on frame of reference judgments. Also, by testing children aged 6-11 and adults, it provides a unique insight into how judgements about frames of reference develop over time.

Following the existing literature we predicted that adults would show independent effects of the relative and intrinsic frames of reference when making judgements about the very same stimuli. This is consistent with their spontaneously activating

both frames of reference. Predictions for children were less clear. If children were dominated by their own position in the world, then we should expect only the relative frame of reference to affect their decisions. On the other hand, if children are influenced by whatever constitutes a “good view” for a given type of judgement, and if the intrinsic frame of reference is a “good view” for our stimuli, then children may only show an effect of the intrinsic frame of reference. Finally, existing evidence that children may use different frames of reference with varying probability on distinct decisions (Bialystok & Codd, 1987; Cox, 1981) suggest that both frames of reference are available in principle to children, and may in fact simultaneously influence decisions on our task.

6.2 EXPERIMENT 5A

6.2.1 *Method*

We showed children and adults pictures of two objects (like those in Figure 6.1) placed close to one another. The pictures were paired with a written sentence indicating that the ball was... “...in front of...” or “... behind the...” other object. Participants had to judge how well the sentence described the picture. By using different arrangements of the ball and the referent object we were able to investigate the importance of different frames of reference on decision-making. Figure 6.1 shows how the intrinsic and relative reference frames can be separately manipulated. For example, if participants rated “the ball is in front of the boy” to be a good description of panel C (in comparison to making the same decision about panel B), then this would suggest they were using the relative frame of reference to help guide judgements.

6.2.1.1 *Participants*

Child participants attended a school in a lower to middle class, predominantly white-British, area of Wolverhampton (UK). Three age groups were tested: 6-7 year olds ($N = 30$, mean age = 7.17, 14 female), 8-9 year-olds ($N = 45$, mean age = 9.08, 24 female) and 10-11 year-olds ($N = 31$, mean age = 11.02, 14 female). Age groups are referred to as 7-, 9- and 11-year-olds herein. Four-five year-olds ($N = 26$, mean age = 5.01 years, 14 female) were also tested as part of a pilot study, but did not produce ratings of acceptability consistent with the use of either frame of reference.

Adult participant were undergraduates and postgraduates from the University of Birmingham who participated in exchange for course credits ($N = 42$, mean age = 20.93, 35 female). All were native English speakers.

6.2.1.2 *Stimuli*

Photographs of sixteen arrangements of two objects were taken using a digital camera. Photographs contained a spherical orange ball and another object (a model chair, a doll or a cup). A doll and a model chair were used as opposed to real objects to allow for creation of a room with no other distinguishing features. The chair provided an example of a Non-Social object with a clear front.

Figure 6.1, shows four picture stimuli from the “Social” condition. Four analogous pictures in which the boy was replaced by a model chair made up the “Non-Social” condition. Stimuli showing the ball and the cup, and stimuli in which the ball was located relatively to the right or left of the other object were presented to check whether participants used the relative and intrinsic frame appropriately when the other

frame of reference was not suitable in decision making. These check stimuli were not used in the final data analysis. A full stimuli set is presented in Appendix 2

A written sentence, either “the ball is in front of the X” or “the ball is behind the X”, where X is replaced by the relevant object name (cup, chair or boy) was displayed underneath the picture. Sentence picture pairs were designed so that for both Social and Non-Social stimuli whether the sentence was an appropriate description for the intrinsic frame of reference and for the relative frame of reference was orthogonally manipulated.

6.2.1.3 Procedure

Adult participants completed the experiment in a testing cubicle and were shown an example slide of a picture and sentence. They were told that they were going to help an alien to learn about how to describe pictures. It was explained that the sentence under the picture was the attempt of the alien (present on the slide) to describe the picture and that their task was to rate how well the alien had done. The scale used to make judgements comprised five cartoon faces ranging from a very sad face to a very happy face (Figure 6.2). After being familiarised with the scale, it was checked that they understood which of the faces referred to good, poor and moderate performance. Participants sat in front of a lap-top computer displaying pictures and statements and gave responses under no time pressure. Adults completed 28 experimental trials and 4 filler trials, recording their ratings on response sheets.

The procedure for children was identical, except for the following changes. Children completed the experiment in a room adjacent to their usual classroom. They made

their choices by pointing to one of the faces and this was recorded by the experimenter. Children completed 14 experimental trials, but no filler trials. These trials were not completed to avoid confusion and due to limited testing time.

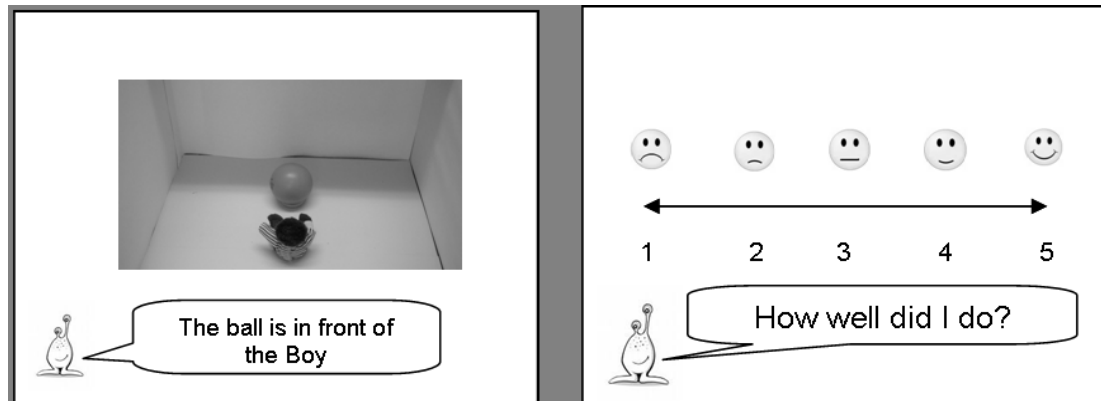


Figure 6.2. Event sequence as experienced by participants. At the start of the experiment, participants were introduced to the alien and told that he was trying to learn how to describe pictures. They then saw pictures paired with a sentence (as above). The sentence was read by the experimenter and then the participant was asked to rate how well the alien had done at describing the picture.

6.2.2 Results

6.2.2.1 Data Coding

Recall that our main interest was in whether effects of both relative and intrinsic frames of reference would be observed across the range of ages tested here, in whether there were any differences between the processing of these reference frames for social versus non-social stimuli, and in whether such effects might themselves vary with age. We had no hypotheses about the interaction between frames of reference. Therefore, since our design was fully orthogonal, we examined relative and intrinsic frames of reference in separate analyses.

This approach meant that a participant's rating of a given picture-sentence pair was analysed twice: once when the picture-sentence pair was coded in relation to the relative frame of reference; and once when the picture-sentence pair was coded in relation to the intrinsic frame of reference. For example, when the stimulus in the left panel of Figure 6.2 is evaluated from the intrinsic frame of reference of the boy, the sentence appropriately describes the relationship between the boy and the ball in the picture. Therefore, for analysis of the intrinsic frame of reference, this picture-sentence stimulus would be coded as "Appropriate". If participants are sensitive to this appropriateness then they should tend to rate the sentence more highly as a description of the picture, compared to picture-sentence pairs that are inappropriate when evaluated from the intrinsic frame of reference. Similarly, when the stimulus in the left panel of Figure 6.2 is evaluated from the relative frame of reference (i.e., the participant's own point of view), the sentence inappropriately describes the relationship between the boy and the ball in the picture. Therefore, for analysis of the relative frame of reference, this same sentence-picture stimulus would be coded as "Inappropriate". If participants are sensitive to this appropriateness then they should tend to rate the sentence lower as a description of the picture, compared to picture-sentence pairs that are appropriate when evaluated from the intrinsic frame of reference.

Data from adults and children were analysed separately due to the differences in methods and number of data points. To establish what the mature pattern of performance was on our task, we first analysed the data from adults.

6.2.2.2 Adults

Intrinsic frame of reference. A 2x2 ANOVA with Intrinsic Reference Frame (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) as within subjects factors revealed a significant effect of the Intrinsic Reference Frame ($F(1, 42) = 241.60, p < .001; \eta p^2 = .86$, Appropriate > Inappropriate) and a significant interaction between the Intrinsic Reference Frame and Stimulus ($F(1, 42) = 14.64, p < .001, \eta p^2 = .26$). There was no main effect of Stimulus ($F(1, 42) = .41, p = .53$).

As can be seen from Figure 6.3, the interaction was explained by the effect of the Intrinsic Frame of Reference being present for both Social and Non-Social stimuli, but being greater when the stimulus was Social ($t(42) = 15.88, p < .001$) than when it was Non-Social ($t(42) = 12.00, p < .001$).

Relative frame of reference. A 2x2 ANOVA with Relative Reference Frame (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) as within subjects factors revealed a significant effect of the Relative Reference Frame ($F(1, 42) = 91.41, p < .001; \eta p^2 = .525$, Appropriate > Inappropriate) and a significant interaction between the Relative Reference Frame and Stimulus ($F(1, 42) = 30.10, p < .001, \eta p^2 = .423$). There was no main effect of Stimulus ($F(1, 42) = .41, p = .53$).

As can be seen from Figure 6.3, the interaction was explained by the effect of the Relative Frame of Reference being present for both Social and Non-Social stimuli, but being greater when the stimulus was Non-Social ($t(42) = 10.70, p < .01$) than when it was Social ($t(42) = 6.44, p < .01$). This was the opposite pattern from that found with the intrinsic frame of reference.

6.2.2.3 Children

Intrinsic frame of reference. A 2x2x3 ANOVA with Intrinsic Reference Frame (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) as within-subject factors and Age (7,9,11) as a between-subject factor revealed a main effect of the Intrinsic Reference Frame ($F(1, 105) = 320.41, p < .001; \eta p^2 = .76$, Appropriate > Inappropriate). There was a trend towards an effect of Stimulus ($F(1, 105) = 3.06, p = .086$, Non-social>Social) and a main effect of Age ($F(2, 105) = 4.02, p = .021, \eta p^2 = .072$; 7>9=11). There was a significant interaction between Age and Intrinsic Reference Frame ($F(1, 106) = 30.61, p < .001; \eta p^2 = .37$), but not between Intrinsic Reference Frame and Stimulus ($F(1, 106) = 2.36, p = .13$). The interaction between Intrinsic Reference Frame, Stimulus and Age ($F(1, 107) = 5.13, p < .01; \eta p^2 = .091$) was significant.

To investigate the 3-way interaction, we conducted separate analyses for each age group. Three separate 2x2 ANOVAs with Intrinsic Reference Frame (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) were carried out. Seven year olds did not show an interaction between Intrinsic Reference Frame and Stimulus ($F(1, 30) = 2.197, p = .149$), but this interaction was observed in 9-year olds ($F(1, 45) = 5.59, p = .023, \eta p^2 = .11$) and 11-year olds ($F(1, 31) = 6.42, p = .017, \eta p^2 = .18$). For both 9-year olds and 11-year olds, the effect of the Intrinsic Reference Frame was significant for Social and Non-Social stimuli, and as for adults, this effect was greater when the stimulus was Social (9-year olds: $t(45) = 12.87, p < .001$; 11-year olds: $t(31) = 14.92, p < .001$) than when the stimulus was Non-Social (9-year olds: $t(45) = 9.76, p < .001$; 11-year olds: $t(31) = 8.25, p < .001$).

Relative frame of reference. An 2x2x3 ANOVA with Relative Reference Frame (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) as within subjects factors and Age (7, 9, 11) as a between-subjects factor revealed a main effect of the Relative Reference Frame ($F(1, 106) = 38.09, p < .001; \eta p^2 = .270$, Appropriate > Inappropriate). There was a trend towards an effect of Stimulus ($F(1, 106) = 3.06, p = .086$, Non-social>Social) and a main effect of Age ($F(2, 106) = 4.02, p = .021, \eta p^2 = .072$). Scheffe corrected post-hoc comparisons indicated that 7-year olds ($M = 3.48, SD = .54$) gave significantly higher appropriateness ratings than 9-year olds ($M = 3.14, p = .035$) and showed a trend towards higher ratings than 11 year-olds ($M = 3.16, SD = .56, p = .072$). The two older age groups did not significantly differ in their ratings ($p = .99$). There were no significant interactions ($F_s(1, 106) < .77, p_s > .38$).

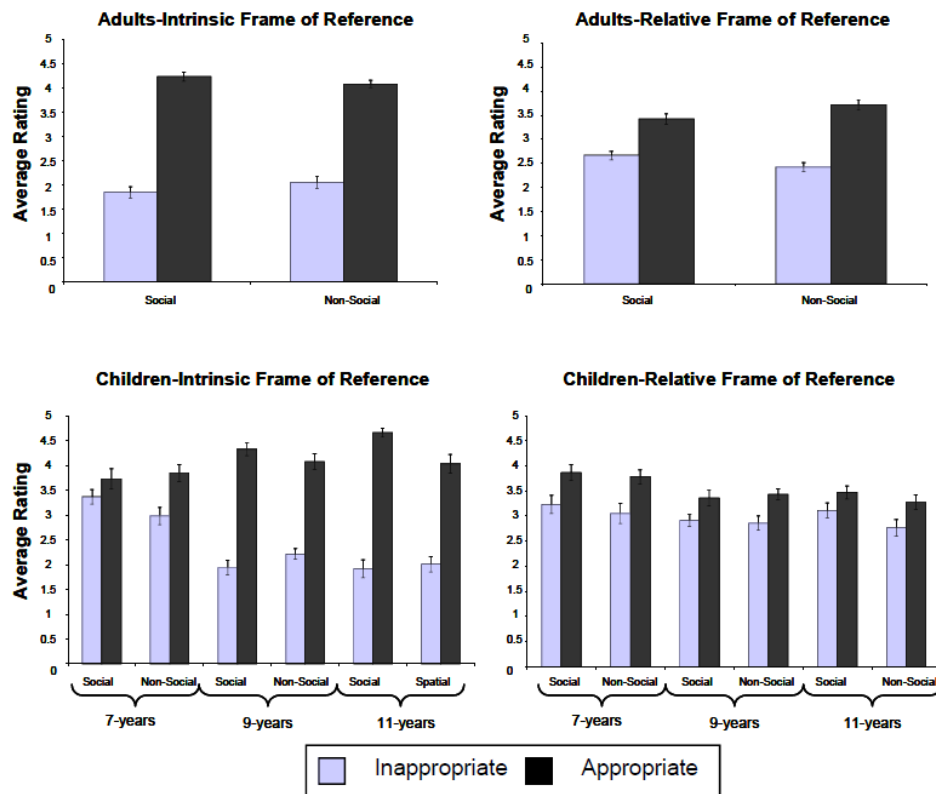


Figure 6.3. Graphs showing performance of children and adults in Experiment 5A. Effect of each Frame of Reference is shown through differences between Appropriate and Inappropriate conditions.

6.2.3 Discussion of Experiment 5A

We identified evidence of spontaneous sensitivity to both the relative frame of reference and the intrinsic frame of reference. In children from the age of seven and in adults, both frames had a significant effect on judgements of the acceptability of statements, whether the referent object was a social or a non-social stimulus. Adults showed a greater effect of the intrinsic frame of reference for social stimuli compared with non-social stimuli, this was observed in older children (9- and 11-year olds), but was not significant in younger children. Conversely, adults showed an enhanced

effect of the relative frame of reference in Non-Social stimuli; this was not shown in children at any of the ages tested.

By investigating these effects using mixed blocks of trials with both social and non-social objects, we emulated the everyday need to make novel judgements about different objects in a flexible way. However, one potential consequence of such a design is that either one of our social or non-social stimuli may have particularly drawn our participants' attention to a given reference frame (or strategy). For example, it is conceivable that the significant effects of the intrinsic frame of reference for non-social stimuli did not reflect typical, spontaneous appraisal of non-social objects, but was, instead, a consequence of participants viewing these stimuli in the same block as social stimuli. For this reason, we conducted a second study in which participants viewed the stimuli in separate blocks, one only containing Social stimuli and the other only Non-Social.

6.3 EXPERIMENT 5B

6.3.1 *Method*

Stimuli and procedure were identical to those used in Experiment 5A, except that social and non-social stimuli were presented in separate blocks. Half of participants completed the social block of trials first and the other half the non-social first. Preliminary analysis revealed that the order of blocks had no effect on the judgements made, ($F_s < 1.43$, $p_s > .23$), and so the data were combined over this factor for further analysis.

6.3.1.1 Participants.

A new sample of children aged 6-11 who attended a school in a lower to middle class, predominantly white British area of Wolverhampton and of Birmingham students completed Experiment 5B. Children tested were from a different school to that used in Experiment 5A. Three age groups were tested (6-7-year-olds, $N=51$, mean age = 7.2, 24 female; 8-9-year-olds, $N = 43$, mean age = 8.7, 21 female; 10-11 year-olds, $N=47$, 26 female, mean age = 10.7). Adults were again undergraduate and postgraduate students from the University of Birmingham ($N=44$, Average age = 20.6, 36 female)

6.3.2 Results

Data were coded in the same way as for Experiment 5A.

6.3.2.1 Adults

Intrinsic frame of reference. A 2x2 ANOVA with Intrinsic Reference Frame (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) as within-subjects factors revealed a significant effect of the Intrinsic Reference Frame ($F(1, 43) = 329.43, p < .001; \eta p^2 = .89$; Appropriate > Inappropriate), and a significant effect of Stimulus ($F(1, 42) = 5.98, p = .019, \eta p^2 = .13$, Social>Non-social), but no interaction between the Intrinsic Reference Frame and Stimulus ($F(1, 43) = 1.01, p = .32$).

Relative frame of reference. A 2x2 ANOVA with Relative Reference Frame (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) as within-subjects factors revealed a significant effect of Stimulus ($F(1, 42) = 5.98, p = .019, \eta p^2 = .13$, Social>Non-social). There was no significant effect of the Relative Reference Frame

($F(1, 43) = .72, p = .40$) and no interaction between the Relative Reference Frame and Stimulus ($F(1, 42) = 1.01, p = .32$).

With the social and non-social stimuli presented in separate blocks, adults no longer showed an effect of the relative frame of reference. This was the case for both Social and Non-social stimuli.

6.3.2.2 Children

Intrinsic frame of reference. A 2x2x3 ANOVA with Intrinsic Frame of Reference (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) as within subjects factors and Age (7, 9, 11) as a between subjects factor revealed a main effect of the Intrinsic Reference Frame ($F(1, 141) = 211.80, p < .001; \eta^2 = .61$, Appropriate > Inappropriate). There was no significant effect of Stimulus ($F(1, 141) = .85, p = .36$), but there was an effect of Age ($F(1, 141) = 10.20, p < .001, 7 > 9 = 11$). There was a significant interaction between Age and Intrinsic Reference Frame ($F(1, 184) = 4.79, p = .01, \eta^2 = .065$), but no other significant interactions ($F(1, 141) < 1.24, ps > .29$).

All age groups independently showed the effect of the Intrinsic Reference Frame (7 year olds: $t(51) = 6.33, p < .001$; 9-year-olds: $t(43) = 8.26, p < .001$; 11-year-olds: $t(47) = 10.60, p < .001$). The interaction between Age and the Intrinsic Reference Frame was the result of 7-year-olds showing a significantly smaller effect of the Intrinsic Reference Frame than 9-year olds ($F(1, 94) = 4.38, p = .039, \eta^2 = .045$) and 11-year olds (7 vs 11: $F(1, 98) = 9.29, p = .003, \eta^2 = .088$). Nine and 11-year olds

showed statistically equivalent Intrinsic Reference Frame effects ($F(1, 90) = .57, p = .45$)

Relative frame of reference. A 2x2x3 ANOVA with Relative Reference Frame (Appropriate, Inappropriate) and Stimulus (Social, Non-Social) as within subjects factors and Age (7, 9, 11) as a between subjects factor revealed a significant main effect of the Relative Reference Frame ($F(1, 141) = 5.88, p = .017; \eta p^2 = .041$, Appropriate > Inappropriate). There was no significant effect of Stimulus ($F(1, 141) = .85, p = .36$), but there was an effect of Age ($F(1, 141) = 10.20, p < .001, 7 > 9 = 11$). There was a significant interaction found between the Relative Reference Frame and Stimulus ($F(1, 141) = 4.41, p = .037, \eta p^2 = .031$), but no other significant interactions ($F_s(1, 141) < .41, p_s > .67$).

The data were split by stimulus type to investigate the interaction between the Stimulus and the Relative Reference Frame. The Relative frame of reference had a significant effect on judgements involving Non-Social stimuli ($t(141) = 3.35, p < .001$), but not for judging those involving Social stimuli ($t(141) = .68, p = .50$).

When participants viewed successive stimuli with the same objects, this altered the pattern of judgements compared with Experiment 5A. Children still showed effects of the Intrinsic frame of reference for both social and non-social objects. However, at all ages, children only showed a significant effect of the Relative frame when the stimulus was non-social.

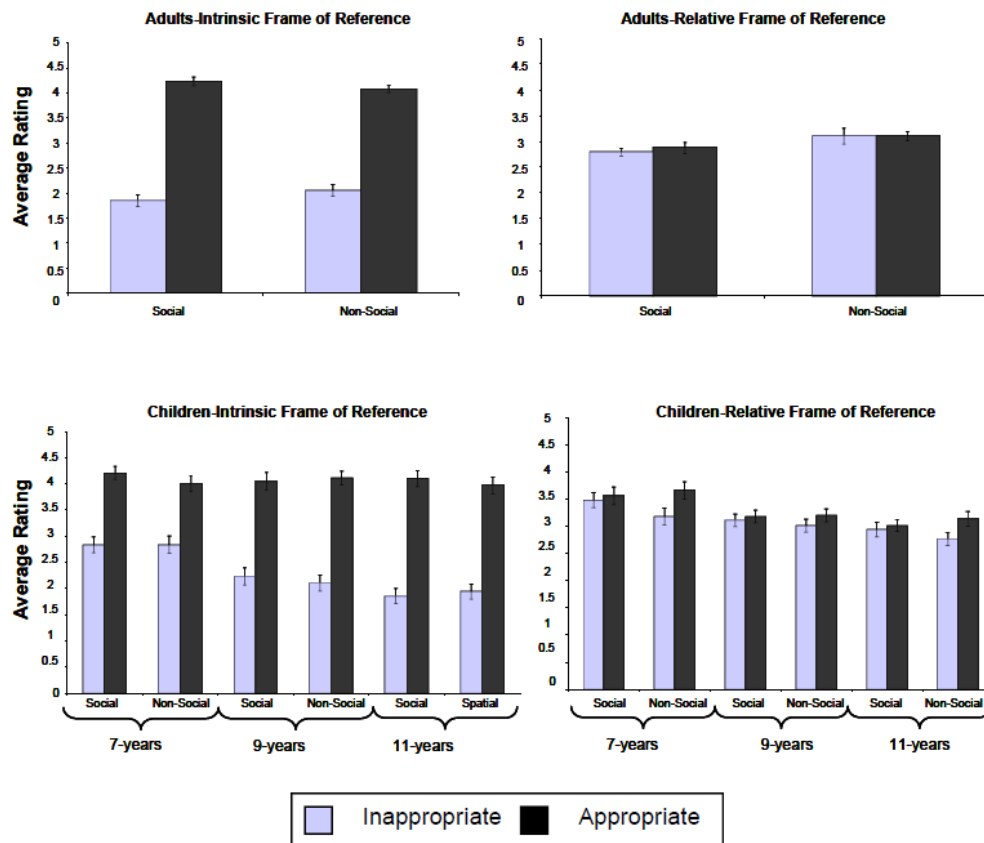


Figure 6.4. Graphs showing performance of children and adults in Experiment 5B. As with Experiment 5A differences between Appropriate and Inappropriate conditions show effects of each Frame of Reference.

6.4 General Discussion

Our results showed three main findings. Firstly, children as well as adults spontaneously use both intrinsic and relative frames of reference to make judgements about the very same stimuli within a single task. Secondly, context of presentation made a difference to participants' sensitivity to the different reference frames: by putting stimuli into blocks we showed that it was possible to cause participants not to use the relative frame of reference in decision making. Finally we found differences in participants' reasoning about stimuli with perspectives versus those purely involving objects. Fronted objects with a perspective caused judgements to be driven more

strongly by the intrinsic frame of reference in comparison with simple fronted objects, and this tendency increased with age.

Experiment 5A showed that both children and adults spontaneously utilised both the intrinsic and relative reference frames when making judgments about the acceptability of verbal statements: when controlling for either reference frame, a significant effect of the other was identified. Importantly, this was the case independently for 4 separate age groups and for both social and non-social stimuli. However, there was developmental change in performance on social compared to non-social trials: 7-year olds performed as if they treated both stimulus types as equivalent, whereas for 9- and 11-year olds, and for adults the effect of the intrinsic frame of reference was stronger for social stimuli than for non-social stimuli. In addition, adults also showed a stronger effect of the relative frame of reference for non-social stimuli than social stimuli.

Experiment 5B investigated the effects on participants of blocking stimuli on the basis of the referent object around which judgements were being made. Even though the stimuli were otherwise identical to those in Experiment 5A, adults no longer showed any influence of the relative frame of reference in decision-making, whilst children only showed the effect of the relative frame of reference when the stimuli were non-social. We characterise this as 'losing yourself in space' as participants' judgements were no longer influenced by their own position, but instead only took account of the intrinsic frame of reference of the object/person about which they are judging.

6.4.1 *Spontaneous multiple reference frame activation in children*

Previous evidence clearly suggests that children are able to use more than one frame of reference when making decisions (Bialystok & Codd, 1987; Cox, 1981; Harris & Strommen, 1972; Nardini et al., 2006). In particular, there seems to be converging evidence that children, like adults, will use the relative frame of reference more regularly for relations such as “above” (Bialstock & Codd, 1987) and they will more regularly use the intrinsic frame of reference for relationships such as “in front” (Bialystok & Codd, 1987; Cox, 1981; Harris & Strommen, 1972). All these studies have used designs with relatively few trials (usually one per condition) and have required children to make definitive judgements by placing an object in front/ behind/ near/ above another object. As such, then, they cannot make any claims as to whether children consider multiple frames of reference when making their decisions. Our experiments are the first to investigate this and in both studies we show evidence of children using the intrinsic and the relative frames of reference to make judgements about the very same stimuli.

6.4.2 *Losing Yourself in Space*

Our findings converge with the findings of Taylor et al. (2001), Bialystok and Codd (1987), and Cox (1981) in showing English speakers to generally favour the intrinsic frame of reference in making judgements about descriptions of in front and behind. Results from Experiment 5A were also similar to the results of Carlson-Radvansky and Irwin (1993), and Carlson-Radvansky and Jiang (1999) in showing that we spontaneously consider multiple frames of reference when making decisions about the acceptability of statements. However, our finding that participants lost sensitivity to the relative frame of reference when stimuli were presented in a series with a single

referent type seems to be without precedent. This seems to be a particularly important finding because it suggests that participants were no longer using their own position in the world to make these decisions. Inhibition is traditionally thought to be required in selecting frames of reference (Carlson-Radvansky & Jiang, 1999), so why is this more successful in Experiment 5B? We suggest two plausible alternatives for a mechanism involved in producing this pattern of results, both caused by repeated exposure of the same fronted object. Firstly, such repeated presentations may make inhibiting the relative frame of reference easier. Alternatively, immersing oneself in a repeated stimulus may stop the relative frame of reference (self perspective) from being activated at all. Although it may seem counterintuitive, such an alternative does have some correspondence with the phenomenon of out of body experiences (Blanke et al., 2005), and possibly in more everyday experiences of becoming immersed in the situations depicted in films or novels.

6.4.3 *His front/Its front/ My front*

Literature on spatial perspective-taking has suggested that making judgements about where an object lies in relation to a person is relatively effortful, relying on active self projection and rotation (Kessler & Thomson, 2010; Kozhevnikov & Hegarty, 2001; Michelon & Zacks, 2006). How then, is it that we appear to perform a similar task relatively easily when we make on-line uses of the intrinsic frame of reference? The answer may lie in social perspective-taking research which has shown examples of much more efficient perspective-taking, even suggesting that simple social perspective-taking may be performed relatively automatically (Samson et al., 2010; Tversky & Hard, 2009; though see Apperly & Butterfill, 2009; Surtees, Butterfill & Apperly, submitted, Chapter 3; for possible evidence that these phenomena may be

limited to simple perspective-taking). It was on this basis that we predicted that manipulating whether a stimulus was inherently social may change how individuals judge the relationships between objects. The most striking evidence for differences in the processing of social and non-social stimuli was evident in Experiment 5B: Children lost their own self-perspective for social stimuli, but not for non-social stimuli. Experiment 5A displayed subtler distinctions between the two stimulus types, with children over the age of 9 and adults showing a stronger effect of the intrinsic frame of reference for social stimuli (and adults showing a stronger effect of the relative frame of reference for non-social stimuli). None of these results alter the fact that in all cases both children and adults seemed spontaneously to take account of the fronts and backs of both objects and people, but there seemed to be a greater sensitivity to *his front* than *its front*.

This conclusion must be tentative for now because all judgements were made about single exemplars of a social and a non-social stimulus, meaning that we cannot guarantee that social stimuli as a group provide more salient fronts, as opposed to the front of the given ‘person’ in our scene. This concern would be addressed by further experimentation using a wider range of social and non-social stimuli. Despite this caution, we believe it is an interesting possibility that spontaneous sensitivity to the intrinsic frame of reference during spatial judgements about fronted objects may be a phenomenon that has its origins in children’s initial spontaneous sensitivity to perspectives.

CHAPTER 7
GENERAL DISCUSSION

Five empirical chapters have been informative to the discussion of roles for controlled and efficient processing of the perspectives of others. In this final chapter I will summarise the main findings to have come from the experiments detailed in the previous chapters, discuss how they relate to one another and to previous findings in the literature, before suggesting some limitations of the approach I have undertaken and how future investigation could help to address these limitations.

7.1 Investigations of Controlled processing in ToM

In Chapters 2-5 participants completed tasks in which they made explicit judgements about other people's perspectives. In Chapters 2-4 this involved visual perspective-taking. In Chapter 5, as well as visual perspective-taking, participants also completed a referential communication task and a task that required them to reason about another's beliefs and desires. Measures from these tasks were then linked to measures of executive functioning. In all these cases perspective-taking can be thought to be controlled as participants made overt answers as to the perspectives of a target or predicted their behaviour on the basis of such perspectives.

7.1.1 Visual Perspective-taking

For both Level-1 and Level-2 perspective-taking I directly measured perspective-taking ability in children from the age of 6-11 and adults. On some trials participants completed these tasks under circumstances when their perspective was consistent with that of the target avatar and on others their perspective was different. Children are able to take the Level-1 visual perspectives of others, even when it diverges from their own, by the age of two (Moll & Tomasello, 2005) and the Level-2 perspectives of others from the age of four (Flavell, Everret, Croft & Flavell, 1981; Flavell, Flavell,

Green, Wilcox 1981; Lempers, Flavell, & Flavell, 1977; Masangkay, McCluskey, McIntyre, Sims-Knight, Vaughn & Flavell 1974). These experiments were clearly, then, not designed to investigate whether children had the conceptual abilities to pass such tasks, but rather to chart the development of cognitive processes for perspective-taking. On direct measures of perspective-taking, both Level-1 and Level-2, there was evidence of improvement with age. Older children and adults responded more quickly and more accurately than their younger counterparts. On all direct measures of perspective-taking children and adults suffered egocentric interference on their judgments. Reasoning about another's perspective was more difficult if it differed from one's own. This egocentrism was statistically equivalent across age groups.

7.1.1.1 Improvements in explicit perspective-taking with age

It is perhaps not surprising that the speed and accuracy of children's judgements of the perspectives of others improve with age. Anyone who has ever had cause to speak to a 4-year old child will likely attest to the fact that their ability to keep up with everyday social situations is really not as adept as that of most adults. What is surprising, however, is the paucity of empirical evidence of this that actually exists. Whilst showing remarkably similar qualitative patterns to adults, the youngest children in the studies completed in Experiments 1 and 2 took twice as long to make their responses as adults, and still made a greater number of errors. One explanation of this may be that this is merely illustrating improvements in general performance. Whilst I did not test participants of different age groups on our non-social control tasks, it would surely be a prediction that these tasks would also show a developmental progression. This is not to say that such a conclusion would be any less interesting. Quantitative development even after concepts are undeniably in place,

as is identified in these experiments, can aid fluency, flexibility and capacity of processing which can surely underlie both quantitative *and* qualitative differences in everyday ToM. Other recent work has suggested that performance in tests of referential communication (Dumontheil, Apperly & Blakemore, 2009) and reasoning about beliefs and desires (Apperly, Warren, Andrews, Grant & Todd, in press) also develops beyond the age at which children can first pass these tasks. There is also emerging evidence of maturation of neural substrates responsible for ToM well beyond the age at which children first pass ToM tasks (Blakemore, 2008). There is, then, strong evidence that children's abilities develop considerably after the age at which they pass standard false belief tasks. Such development may not, necessarily, allow them to pass new or more complicated tasks, but may be important in successfully negotiating complicated and rapidly developing social situations.

7.1.1.2 Egocentrism

Egocentrism has long been linked to the errors made by young children who fail ToM (Birch & Bloom, 2007) and perspective-taking (Piaget & Inhelder, 1956) tasks. When children make errors, they do not do so at random, but rather, they answer in line with their own perspective on a given scene (Piaget & Inhelder, 1956; Wimmer & Perner, 1983). It is also the case that when adults make judgements without certain outcomes they show egocentric biases (Bernstein, Atance, Loftus, & Meltzoff, 2004; Birch & Bloom, 2007; Michell, Robinson, Isaacs & Nye, 1996; Nickerson, 1999; Royzman, Cassidy & Baron, 2003). As the methods of experiments with different age groups have differed so dramatically it is not clear if adults' egocentric biases and children's egocentric errors are related in any but the most superficial way.

Results from Experiments 1, 2 and 3 of this thesis suggest that egocentrism of the form shown by young children really is evident when older children and adults complete tasks similar to those failed by young children. Adults showed egocentric biases in their response times and error rates on tasks passed by 2-year olds (Level-1 perspective-taking) and 4-year olds (Level-2 perspective-taking). The levels of egocentrism experienced by children from the age of 6 years to adulthood showed statistically equivalent effects. This suggests that the mechanism responsible for egocentric errors in unsuccessful perspective-takers is residual in successful perspective-takers and manifests itself as egocentric biases. That is not to say that *all* egocentrism shown in adults is necessarily linked to egocentrism in children, rather that at least part of it is.

7.1.1.2.1 Routes to Egocentrism- Egocentric anchoring and adjustment

One way of calculating the perspective of another is to use an appropriate heuristic to generate an initial candidate for what they see, think, desire or believe (Epley & Gilovich, 2002). Often a suitable initial candidate for this may be our own view, knowledge or beliefs (Epley, Keysar, Van Boven & Gilovich, 2004). Of course our own perspective is regularly different to that of others and we should be able to use our knowledge about the other person to improve our estimate; in fact this requirement is a crucial factor in the design of all ToM experiments. Egocentric anchoring and adjustment suggests that this is done through a series of mini adjustments until we create a plausible candidate perspective for other. Such a “plausible candidate” is often found closer to one’s own perspective than a truly normative response. Such insufficient adjustment is one explanation for the observation of egocentric biases.

Epley and colleagues (Epley et al., 2004) suggest that egocentric anchoring and adjustment may explain egocentrism in perspective-taking. In one example (Epley et al. 2004), participants heard a recorded message which could be interpreted either as sincere or sarcastic. Participants were influenced by their own knowledge of the sincerity of the person leaving the message in judging how likely the intended recipient would be to interpret the message as sincere or sarcastic. This suggests that participants' own knowledge affects their judgements, causing them to provide non-normative responses. Epley and colleagues showed that egocentrism increased with time pressure and when participants performed a nodding action (suggesting they were being influenced towards accepting an insufficient adjustment) and proposed this as evidence of adjustment.

It is clear that such an anchoring and adjustment strategy, be it conscious or not, could explain the occurrence of egocentric biases, but does it do so in Experiments 1-3? Imagine in our perspective-taking tasks, participants first calculate their own perspective, be it 3 circles, or that the figure looks like a number 6. If a participant were to adopt this strategy, then anchoring and adjustment would predict inconsistent trials to be more difficult as these are the only trials in which participants have to make any adjustments at all. This is exactly what was found suggesting anchoring an adjustment is a plausible interpretation of the results. However, whilst consistent with our findings, there is no specific evidence showing that adjustments are used in our tasks.

7.1.1.2.2 Routes to Egocentrism- Interference

Anchoring and Adjustment, whilst influential in social psychology and in explaining adults' estimates, has not to my knowledge been used as an explanation of egocentric errors made by children in classic ToM tasks. Such errors are more frequently explained by the Curse of Knowledge (Birch & Bloom, 2003), or by Realist biases (Mitchell et al., 1996). Whilst these explanations are not particularly clear about the nature and time course of self and other perspective-taking, what is clear is that these explanations do not propose that self-perspective is used as the necessary starting point in calculating the perspective of another. These theories suggest that one's own perspective is a hindrance on perspective-taking. There are clearly, at least, two ways in which avoiding one's own perspective could be particularly difficult in taking that of another. Firstly, it could be hard to calculate and impute the perspective of another in the light of one's own perspective. This way of thinking is most in line with the original Piagetian concept of egocentrism as a fixation which prohibits or interferes with further processing (Piaget & Inhelder, 1956). Another alternative is that self perspective is processed automatically and once we have calculated the perspective of another it is simply hard to ignore our own view when making a response. Such an interpretation seems most in line with a view of ToM and executive functions proposed by Leslie and colleagues (Leslie & Polizzi, 1998; Scholl & Leslie, 1999; See also Apperly, Back, Samson & France, 2008; for a case where this must definitely be the case as participants are explicitly told a target's perspective). Both of these possible forms of interference would be in line with the findings of egocentrism in Experiments 1-3. It may be hard to generate the perspective of other as seeing a 9 when faced with a 6, or difficult to respond that another sees a 9 in the light of the fact you currently see a 6 (or both).

7.1.1.2.3 Resolving which route(s) to egocentrism is responsible for the findings

Experiments 1-3 clearly showed egocentrism as a central feature of older children and adults' judgements of the perspectives of others. This is in itself interesting and informative about the nature of the demands placed on effortful perspective-taking. It seems that at least one reason why ToM can require controlled and effortful processing is in allowing for ignoring one's own perspective (as confirmed by Qureshi, Samson & Apperly, 2010 who showed egocentrism to increase under dual task conditions). With regards to visual perspective-taking experiments of the kind detailed in this thesis, theories of egocentrism make similar predictions. This is largely because the key difference between the different interpretations rests on time course, as opposed to outcome.

One obvious way to investigate the time course of processing of perspectives in general, and divergent perspectives in particular, is by use of Electroencephalography (EEG) and in particular measures of Event Related Potentials (ERPs). ERP investigations allow for the investigation of neural responses to different conditions and provide resolution accurate at the millisecond level. This allows for understanding how, and more importantly when, different conditions are differentiated, both cognitively and neurally. ERP measures have been used in a number of studies of ToM. Appropriate time-locking to a given stimulus is often difficult using traditional measures of ToM, and most studies using such methods have only found late slow wave components over the left frontal cortex in comparison to false photograph conditions (e.g., Liu, Meltzoff & Wellman, 2009; Sabbagh & Taylor, 2000). Such findings are limited in how informative they are about the cognitive and neural time

course of ToM. Paradigms such as those I have used in this thesis would be ideal for use in combination with ERPs because the stimuli are presented at a very specific time point. Therefore it can be determined that this is when perspective-taking commences.

A recent study (McCleery, Surtees, Graham & Apperly, submitted) used the measure of Level-1 visual perspective-taking detailed in Experiment 1 to examine the time course of this kind of perspective-taking. This study showed the temporo-parietal cortex to calculate and represent the perspective of self versus other and, later, the right frontal cortex to resolve conflict between perspectives during response selection. From this, we suggested that the egocentric effects found in our Level-1 perspective-taking tasks may be the result of having to inhibit a strongly held self-perspective in making a response for the perspective of other. There was no evidence that self perspective was used in calculating other perspective. Consistency of perspective was resolved by the right frontal cortex *after* the temporo-parietal cortex had indexed self and other perspectives.

7.1.1.2.4 Links between egocentrism and executive functions

Whilst one interesting question related to egocentrism is the functional time-course of the processing involved and what this says about potential processing strategies, another is what allows us to avoid being entirely egocentric. In Experiment 4, we investigated links between egocentrism on a number of tasks and the executive functions in middle childhood. We showed that complex inhibitory abilities and the ability to switch between tasks predicted an individual's level of egocentrism in visual perspective-taking. Egocentrism in belief reasoning was related to working memory

and inhibition. These findings suggest that the executive functions do continue to play a role in theory of mind beyond the age at which children first pass theory of mind tasks. Whilst not inconsistent with purely conceptual accounts, such a finding is necessary for accounts of ToM relating to executive performance (Leslie, German & Polizzi, 2005) and executive competence (Russell, 1996).

7.2 Efficient Processing of Perspectives

Throughout this thesis I have made the case for efficient mechanisms for ToM. I believe that success by infants on tasks that seem to require ToM dictates this (Kovacs, Teglas & Endress, 2010; Onishi & Baillargeon, 2006; Sodian, Theormer & Metz, 2007; Song & Baillargeon, 2008; Southgate, Senju & Csibra, 2006). I have also made the case for such early developing and efficient mechanisms being limited. To describe and explain these limits, thus becomes crucial in developing a full understanding of ToM. Such investigations should not only focus on infants, but also on bringing convergence from findings with older children, adults and non human animals.

7.2.1 Efficient/Automatic Processing of Visual Perspectives

In Chapter 1, I set three criteria for visual perspective-taking to be considered efficient/ automatic: perspective-taking should occur in spite of prior information that it is not the task; such perspective-taking should actively hinder performance and finally the same effects should not be found when stimuli are inherently non-social. In Chapter 2 we investigated whether children's Level-1 perspective-taking satisfied these criteria. On half of trials, children aged 6-11 and adults took their own perspective on a given scene. Importantly, participants were cued that it was their own

perspective they were taking prior to the trial, and even what they might expect that perspective to be, thus satisfying our first criterion. The difference between Inconsistent and Consistent trials is evidence that taking the avatar's perspective was hindering task performance, as there was a cost to inhibiting the avatar's perspective when it did not match the participants' own. Experiment 1B demonstrated that this effect was not replicated using non-social stimuli. Any interference caused by switching between tasks was not as great as caused by ignoring an alternative perspective. Whilst the findings from adults replicate the findings of Samson, Apperly, Braithwaite, Andrews & Bodley-Scott (2010), using a different method, the findings for children as young as 6 are completely novel. Level-1 perspective-taking is somewhat automatic even in 6-year olds. These results suggest that the findings of Samson et al. (2010) cannot be explained by a highly practiced adult perspective-taking mechanism.

7.2.2 Level-1 vs. Level-2 Perspectives

Chapters 3 and 4 sought to investigate whether Level-2 perspective-taking is in any way automatic. That is to say, if people automatically calculate whether others see a given object, do they also calculate how they see it? Experiment 2 suggests that they do not. Children showed no interference from the perspective content of an avatar in a scene. Adults, appeared to do so, but further investigation suggested they had automatised some incidental aspect of the task. Experiments 3A and 3B directly examined adults' Level-1 and Level-2 perspective-taking with exactly the same stimuli. In this case, adults did seem to show some level of interference from the Level-2 perspective of the avatar. This interference was not, however, any greater than the interference from an arbitrary task of mentally rotating to a given position. It

seems clear, then, that Level-2 perspective-taking does not satisfy the criteria set out for an automatic process in Chapter-1. In Chapters 3 and 4 I discussed the importance of this finding and proposed that the Level-1/Level-2 distinction may approximate to a signature limit on ToM. Evidence of limits on adults' ability to efficiently take the visual perspectives of others seems to converge with the limits to precocious abilities shown by infants and non-human animals. Whilst absence of evidence of Level-2 perspective-taking is not evidence of absence, this convergence of evidence does suggest that this may be a limit on efficient mechanisms for perspective-taking in general.

7.3 Limits to and future work on the investigation of cognitive processes for Perspective-taking

The direct investigation of the cognitive processes involved in ToM is relatively novel. It is clear, then, that I should acknowledge what this investigation of automatic and controlled processing in visual perspective-taking lacks and outline a course of future research that would address these areas.

Throughout this thesis I have spoken about ToM as a broad and varied social cognitive apparatus, responsible for a broad range of processes aimed at addressing a wide variety of everyday problems. A large part of this thesis has been devoted to one specific problem that ToM is required to solve, specifically how we judge what others see when they see differently from ourselves. It should hopefully have been clear throughout this thesis that I do not take it as a given that all aspects of ToM will be achieved by the same processes, in fact I think this is highly unlikely. To understand how a process operates, the cognitive resources it demands and the limits within

which it operates, careful attention is needed to manipulate the demands of a given task, the participant groups involved and the control conditions used. It would have been desirable to investigate a variety of processes within ToM, but certainly not if what was lost was the depth of investigation into a given process. Investigating visual perspective-taking, rather than another aspect of ToM was dictated by the nature of the evidence currently available. In many ways visual perspective-taking is the area of ToM with the most clarity as to the success achieved by different participant groups. That this is the case is quite remarkable considering the lack of attention placed on visual perspective-taking in comparison to belief reasoning. That infants and non-human animals can track some elements of the visual perspectives of others (Flombaum & Santos, 2005; Hare, Call & Tomasello, 2001; Luo & Baillargeon, 2007) is largely accepted within the field. Also, recent findings of automaticity in visual perspective-taking (Qureshi et al., 2010; Samson et al., 2010) may be the only clear evidence that ToM occurs automatically, although there is strong evidence of *spontaneous* processing of more complex aspects of ToM (Cohen & German, 2009; Kovacs et al., 2010). Thus investigating the limits of visual perspective-taking and how it develops is crucial in investigating whether such a process forms part of a core cognitive ToM.

Even within visual perspective-taking, there have been limits to the investigations in this thesis. Firstly, the youngest children investigated have been aged 5. Younger children were tested in a pilot study, but struggled to cope with incidental task demands. It may seem unnatural, then, to promote this as being relevant to questions around the success of infants (not to mention non-human animals!) At several points in this thesis, I have defended the notion that mechanisms identified may be those

responsible for success in infants. The lack of qualitative developmental change in Level-1 perspective-taking and the fact that the similar process of Level-2 perspective-taking has not been automatised, even in adults, lead me to believe that Level-1 perspective taking is likely to be *originally automatic*. Further evidence of automaticity in even younger children would be informative as it would clarify whether automatic perspective-taking is truly how infants pass ToM tasks that employ indirect measures.

In Chapter 3 it was suggested that the Level-1/Level-2 distinction is ill-defined. It will, hopefully, have been clear why this loose approximation was maintained for our investigations. Equally, it is clear that further theoretical and experimental work is required to effectively refine this signature limit. That calculating the number of dots an avatar can see falls within the limits of an efficient perspective-taking process, but calculating how a numeral appears to an avatar does not, still leaves open many possibilities for the precise definition of the signature limit on visual perspective-taking. One of the positive aspects I see in this line of research is that any definition of a signature limit on ToM would afford specific predictions. Further to this, there should be some investigation into other limits on this automatic perspective-taking. It seems implausible that in a crowded situation people are automatically taking the perspectives of everyone else (even for Level-1 perspectives), but how are relevant perspectives selected? Such a decision also hints towards another aspect of the limits of processing visual perspectives automatically, that is of the requirements of the stimulus itself. We know, so far, that a non-social stimulus does not precipitate the same degree of effect (Samson et al., 2010; Surtees & Apperly, in press, Chapter 2). We also know that an avatar can be facing perpendicular to the participant, or more

head-on. What is not clear is what specific features of this stimulus drive the effect. An interesting future line of investigation could look to isolate and vary the effects of eye gaze, head direction and body direction to see which of these features really triggers automatic visual perspective-taking. Further to this, with recent studies showing that belief states may have some privileged access to processing of social information (Teufel et al., 2009), investigation could identify whether this is the case for visual perspective-taking. Would participants still suffer interference from his perspective if they believed him to be blind? If this were the case, then participants would be responding to a purely stimulus-driven mechanism. If this were not the case, then this would suggest that some form of top-down control could prevent automatic processing. Importantly, though it may be the case that only certain systems may have access to controlling such a mechanism. For instance, in the way that Teufel et al. (2009) found belief states to *access* processing of seemingly automatic eye-gaze cueing (where deliberate control fails), it may be that such belief states can influence automatic perspective processing.

7.4 Spatial Perspectives

In Chapter 1, I proposed that there were several lines along which perspectives could be discriminated and also proposed that a place should be found for spatial frame of reference judgements within such distinctions. In Chapter 6 I investigated frames of reference using social and non-social stimuli. In Experiment 5A, where children and adults viewed stimuli in mixed blocks (seemingly the most naturalistic variant of our task), all of our age groups showed sensitivity to both their own perspective and that of a subject/object in a scene. This is the first time such an effect has been shown in children. With repeated presentation of a single referent participants no longer

considered their own position in the scene in making their judgements, provided another perspective was present. These effects were modulated by whether the referent was a subject with a perspective of his own, or merely a fronted object. Most notably, children only lost sensitivity to their own perspective in cases where they were confronted with another subject.

In Chapter 6 itself, we discussed the significance of these findings, leaving here the vital point to suggest links between these findings and those within the rest of this thesis. Importantly, where do findings from spatial frame of reference tasks fit in with general considerations of when perspective-taking may be controlled or efficient? In both of the experiments in Chapter 6 participants made decisions under no time pressure, so clearly, these decisions gave opportunity for cognitive control. However, on the other hand, participants were never asked to explicitly consider the perspectives in the scene; therefore, any perspective-taking was incidental, spontaneous and possibly even automatic. In both experiments, participants incorporated the perspectives of both agents and objects into their decision making and Experiment 5B even identified a circumstance under which participants stopped using their own perspective at all in their judgements. On the one hand, it might seem puzzling that they did so, given the fact that processing perspectives is often found to be effortful with a cost to ignoring our own viewpoint. Added to this, previous research has found that, for above/below judgments, the relative and absolute frames of reference seem to be favoured over the intrinsic frame of reference (Carlson-Radvansky & Irwin, 1993). So why is it that participants used the intrinsic frame of reference so heavily for Front/Back judgements? One possibility is that these judgements utilise the efficient mechanism for perspective-taking that I proposed in

Chapters 2-4 and thus require only limited cognitive resources. In tracking the content of another's perspective, one is most commonly, by default, tracking what objects are in front of them and this may impact on judgements of spatial frames of reference.

7.4.1 Future work on psychological and spatial perspectives

Chapter 6 provides further evidence that investigating how we judge spatial relationships between people and objects may be important in understanding judgements of psychological and spatial perspectives in general (Kessler & Thompson, 2009; Michelon & Zacks, 2005; Zwickel, 2009). The current method tested children as young as 6-years old, but future work would be crucial in investigating whether decisions about spatial and psychological perspectives have a similar origin earlier in development. Whilst overt rating of linguistic statements in younger children would prove difficult, indirect measures would be possible. Taylor et al (2001), in a study using ERPs, showed that adults elicited an N-400 component, which is thought to be evidence of semantic integration, when viewing frames of reference which contradicted one another. This promotes the idea that even when participants make a clear response using one frame of reference they have difficulty integrating information from an incongruent frame of reference. There is no reason why a similar paradigm could not be used with young children and certainly no reason why agents could not be used instead of fronted objects. Such an experiment would allow us to track the development of frame of reference activation: Is it originally *automatic*, or *automatised*? Do socially driven judgements promote use of the intrinsic frame of reference, or is the intrinsic frame of reference a cue to perspective? Testing whether infants and young children would show a preference for choosing objects located in front of other objects/people may also impact on this question. This

would allow us to, to some extent, isolate the effects of frame of reference and frontedness. If we are automatically driven by the front of an object (related to a perspective), we would predict finding implicit preferences for objects located in front of other objects. If we are driven by the intrinsic frame of reference of an object, those items behind should be just as salient.

As well as testing younger children, there is still much we don't know about how adults integrate frames of reference and perspectives. Including multiple perspectives may provide for further information on how perspectives influence judgements. If another person sees a scene differently from us, are we more likely to describe the scene in terms of the intrinsic frame of reference which is the same for all? Another obvious future experiment would be to combine the visual perspective-taking paradigm used in Chapters 2-5 with fronted objects. It would be interesting to understand whether spatial perspectives may be calculated automatically- we know that frames of reference are (Carlson-Radvansky & Jiang, 1999), but there is no evidence that content is ascribed from this. In such an experiment, fronted objects, potentially both social and non-social, could be used in place of our avatar, with participants making judgements about how many objects are located in front of the fronted object.

7.5 *Conclusions*

This thesis has investigated control and efficiency in ToM. Chapters 2-4 focussed on where the lines are drawn between these two elements when looking at an early developing ToM ability, visual perspective-taking. Controlled perspective-taking investigated in these tasks was always subject to egocentric interference. Efficient

perspective-taking was limited to Level-1 representations, and had developed at least by the age of 6. I suggest that an efficient mechanism is responsible for the success of infants, non-human animals and adults under a cognitive load. This process is critically limited. Development is needed to overcome egocentrism when giving direct responses and to aid flexibility. Children's ability in ToM tasks improves over time, even once they have developed all the requisite conceptual apparatus to pass the full gamut of ToM tasks children become faster and more accurate. Chapters 2 and 3 showed clear evidence of this, and Chapter 5 suggested that improving resources in inhibitory control and task switching may be responsible for some of this development. Limits and features of perspective-taking are unlikely to be solely linked to executive abilities: The specific nature of the representation required, the given task demands and the nature of the perspective-generating stimulus may well also prove important in regulating performance.

When people talk about perspectives, generally, we assume an individual's mental picture of the world. On the other hand, research from spatial perspective-taking provides fascinating insight into the processes involved in attributing the position of an object relative to another person (Kessler & Thompson, 2009; Michelon & Zacks, 2005; Zwickel, 2009). In Chapter 6 we directly compared judgements involving a self- and other- perspective in scenes containing a social agent or a fronted object. The major features of frame of reference judgements were similar for both kind of referent, both self and other perspectives were considered in making judgements, but the nature of the stimulus did modulate ratings, and always in the direction of more social stimuli promoting the perspective of other.

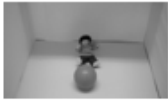
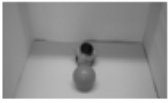


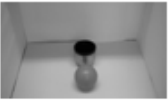
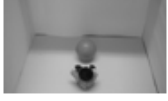



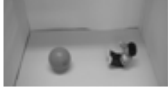
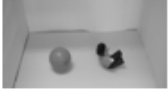


As much as I hope that this thesis has answered some questions regarding perspective-taking and ToM more generally, it has also raised many. Questions about how we calculate and represent the psychological and spatial perspectives of self and other remain very strongly in focus. Processes for and routes towards efficiency in ToM are yet to be fully described and the exact similarities and differences between the usage of agents and objects in frame of reference judgements remains somewhat unclear. This challenge provides an exciting basis for future research which should test children and adults' abilities in tasks that allow for careful offline consideration, but also tasks that test performance in rapidly moving situations.

8. APPENDICES

Appendix 1: Mean Response Times and Error Rates for Experiments 3A and 3B

		PERSPECTIVE TAKING		PROJECTION	
		CONSISTENT	INCONSISTENT	CONSISTENT	INCONSISTENT
		Mean (S.E)	Mean (S.E)	Mean (S.E)	Mean (S.E)
LEVEL-1 DIRECT MEASURE	RESPONSE TIME (ms)	654.42 (31.34)	746.09 (33.32)	740.24 (36.98)	834.68 (44.49)
	ERRORS (%)	3.08 (1.08)	9.01 (1.72)	5.75 (2.23)	12.19 (2.46)
LEVEL-1 INDIRECT MEASURE	RESPONSE TIME (ms)	630.13 (26.16)	730.71 (32.30)	673.13 (27.92)	745.15 (26.18)
	ERRORS (%)	3.33 (1.50)	12.89 (2.68)	3.67 (1.53)	10.20 (1.79)
LEVEL-2 DIRECT MEASURE	RESPONSE TIME (ms)	909.86 (51.32)	1179.74(47.34)	1278.27 (90.63)	1501.19 (81.86)
	ERRORS (%)	10.99 (2.60)	14.46 (1.90)	10.67 (2.77)	15.36 (2.13)
LEVEL-2 INDIRECT MEASURE	RESPONSE TIME (ms)	796.62 (38.54)	943.15 (42.29)	950.71 (61.66)	1128.24 (69.41)
	ERRORS (%)	5.01 (1.25)	10.14 (2.57)	5.63 (1.13)	7.85 1.63)

Appendix 2: Complete list of picture stimuli for Experiments 5A and 5B

		Position of Ball with regard to Intrinsic FoR				
		In front	Behind	In front	Behind	Neither
Position of Ball with regard to Relative FoR	In front					
	Behind					
	Neither					
		Social Referent		Non-Social Referent		

All pictures used within both Experiment 5A and Experiment 5B. Pictures where the ball was neither in front nor behind the other object with regard to a given frame of reference were used to check participants’ use of the alternative frame of reference.

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